Astrophysics

PROGRAM OVERVIEW

NASA

Contents

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Astrophysics

PROGRAM OVERVIEW

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NASA

1. Humanity and the Cosmos

Nature offers no greater splendor than the starry sky on a clear, dark night. Silent, timeless, jeweled with the constellations of ancient myth and legend, the night sky has inspired wonder throughout the ages.

Astronomy, born in response to that wonder, is sustained by two of the most fundamental traits of human nature: the need to explore, and the need to understand. Through the interplay of discovery and analysis, answers to questions about the Universe have been sought since early times, for astronomy is the oldest science. Yet it has never, since its beginnings, been more exciting or vigorous than it is today.

Through modern astronomy, we now know that we are connected to distant space and time not only by our imagination, but also by a cosmic heritage: the chemical elements that make up our bodies were created billions of years ago in the hot interiors of remote and long-vanished stars. Their hydrogen and helium fuel finally spent, these primeval stars met death in cataclysmic supernova explosions, scattering afar the nuclei of heavier elements synthesized deep within their cores. Later, drawing upon matter enriched in these nuclei, our Solar System formed, endowed with the carbon, oxygen, and other elements necessary for the evolution of life on Earth.

Although ours is the only planetary system of which we can be certain , others may surround some of the two hundred billion stars in our Galaxy. Elsewhere, beings with an intelligence surpassing our own may also stand in wonder before the majestic night sky. If such beings exist—possibly even attempting to communicate with us across the vast expanses of interstellar space—they, too, must share our cosmic heritage.

Humanity and the Cosmos

2. A Golden Age of Discovery

In all of history, there have been only two periods in which our view of the Universe has been revolutionized within a single human lifetime. The first occurred three and a half centuries ago at the time of Galileo; the second is now under way.

The recognition of our cosmic heritage is a relatively recent achievement in astronomy—one of many such insights that our generation alone has been privileged to attain. The discoveries of the past 30 years have radically changed our concepts of the origin and evolution of stars, galaxies, and the Universe itself.

The 1960s saw the discovery of quasars, X-ray sources outside the Solar System, microwave radiation left over from the "Big Bang" birth of the Universe, rapidly spinning neutron-star pulsars, high-energy celestial gamma rays, and complex organic molecules in interstellar gas clouds. The Universe, formerly thought to be slowly changing and uneventful, was suddenly recognized to be highly dynamic and teeming with explosive, high-energy processes of extraordinary violence.

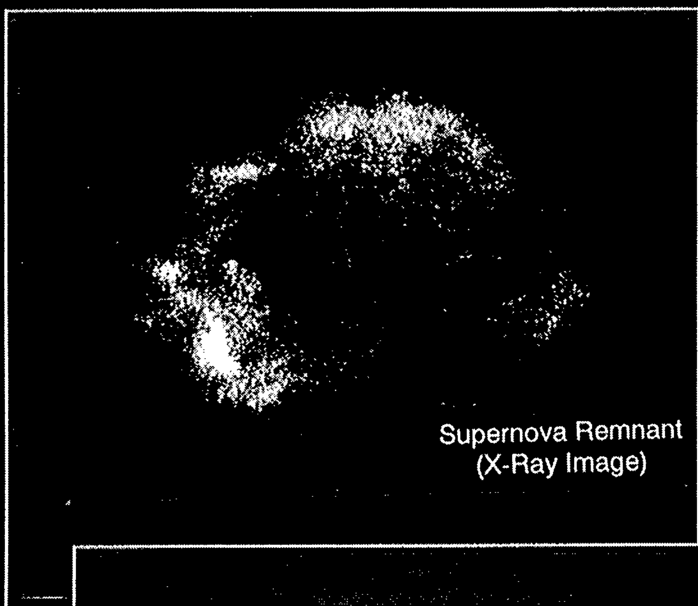
The 1970s continued this rapid pace of discovery, producing such findings as the thermonuclear explosions of matter accreted by neutron stars in double-star systems, the heating of the interstellar medium to millions of degrees by supernova detonations, the existence of rings around Uranus and Jupiter, powerful bursts of gamma radiation from unknown sources, and the widespread presence of stellar "winds" propelling matter into space at rates sufficient to alter the course of stellar evolution.

The decade of the 1980s added its own revelations and surprises, including the finding of quasars near the edge of the visible Universe, the bending of light rays by galactic "gravitational lenses," the large-scale organization of galaxies into vast filamentary structures, observations of warm disks of matter orbiting nearby stars—possibly planetary systems in the process of formation—and the inference of unseen "dark matter" within and between galaxies that may account for 90 percent of the mass of the Universe.

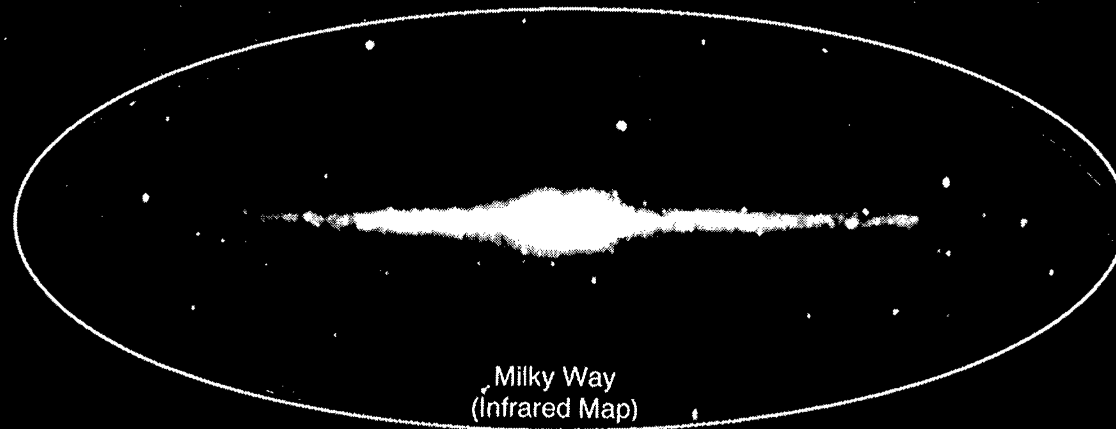
The decade of the 1990s, which has already produced new evidence for ongoing star formation and for the presence of supermassive black holes at the centers of some galaxies, promises to extend this pattern of discovery into even more exciting research directions.

Optical and radio telescopes on the Earth's surface originally furnished hints of some of these findings, and ground-based observations will continue to be important for the analysis and understanding of many cosmic phenomena. However, the Astrophysics program of the U.S. National Aeronautics and Space Administration has been perhaps the single most important agent of these achievements.

A Golden Age of Discovery

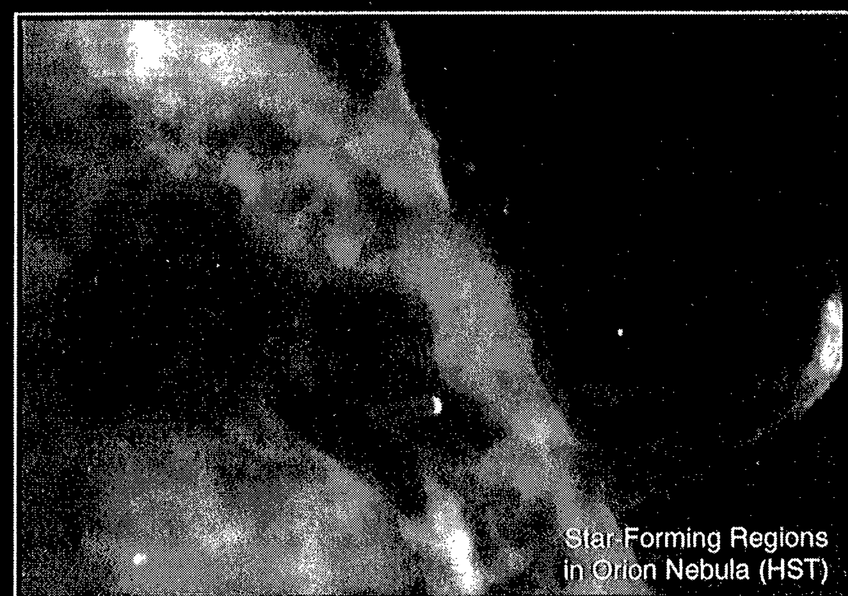


Supernova Remnant
(X-Ray Image)



Milky Way
(Infrared Map)

Center of Galaxy NGC 4261
A Black Hole? (HST)



Star-Forming Regions
in Orion Nebula (HST)

3. Research Across the Electromagnetic Spectrum

NASA's Astrophysics program is designed to study the origin, evolution, and fate of the Universe by making investigations across the entire electromagnetic spectrum.

Different types of cosmic phenomena generate different kinds and levels of electromagnetic energy at various stages in their evolution. For example, dust clouds emit infrared radiation as they collapse to form stars and galaxies, and stars in their later, highly energetic phases may emit X-rays and gamma rays.

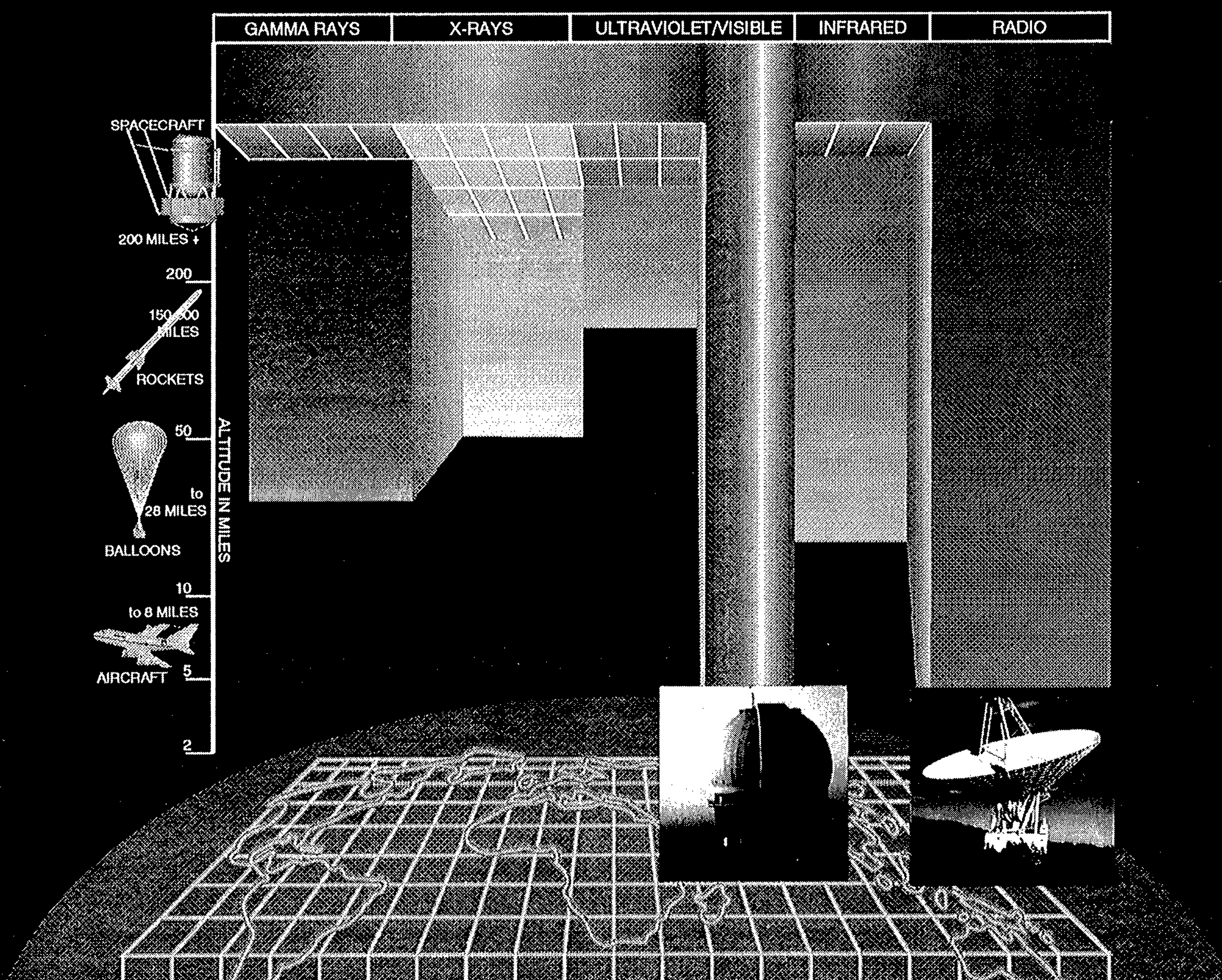
Only visible light and radio waves (together with just a few wavelengths of infrared and ultraviolet radiation) can penetrate the Earth's atmosphere. Even then, atmospheric turbulence distorts astronomical observations made from the Earth's surface. Astronomical observations in all regions of the spectrum—including the visible region—are therefore most effectively made from observatories in space. Only by spanning the spectrum and observing from space can scientists learn about every stage of the origin and evolution of the Universe.

NASA's major contribution to modern astrophysics has been to place powerful new instruments in Earth orbit for sensing gamma rays, X-rays, ultraviolet, visible and infrared radiation without interference from the absorbing, distorting atmosphere. The Hubble Space Telescope (HST) has discovered faint protoplanetary disks around some nearby stars and provided evidence for black holes at the hearts of several galaxies. The Cosmic Background Explorer (COBE) has detected slight fluctuations in cosmic background radiation temperature that explain the origin of early structure in the Universe. X-ray observations by the Roentgen Satellite (ROSAT), a collaborative U.S.-German-British mission, have yielded evidence of the dark matter believed to make up most of the mass in the Universe.

In addition to the vantage point of space, observing the Universe across the spectrum requires a broad array of instruments employing different detection techniques. To deploy a full complement of investigations, the Astrophysics Division sponsors missions ranging from the small and highly focused—borne by balloons, sounding rockets, aircraft, and small spacecraft—to the large and comprehensive—the "Great Observatories." Combined with ground-based radio observations, these missions cover the spectrum and provide astronomers with the wide range of observational tools they need to do their work.

Astrophysics

Research Across The Electromagnetic Spectrum



4. Science at NASA

Beginning with the launch of NASA's first Explorer satellite in 1958, scientific research has been a mainstay of United States space exploration. Astrophysics is one of six scientific disciplines currently supported by NASA.

NASA pursues three interrelated but conceptually distinct programs:

(1) Manned spaceflight, supported by the Space Shuttle and Space Station, for human exploration of space and the Solar System;

(2) Research in aeronautics, advanced technology, and the commercial use of space, designed to further United States technological prowess and industrial competitiveness in the international marketplace; and

(3) Research on a variety of scientific fronts, all of which make use of space vehicles supported by ground-based research, analysis, and data-interpretation programs.

Historically, the first two of these programs have accounted for about 80 percent of NASA's budget. All three are supported by an extensive infrastructure involving expendable launch vehicles and their associated facilities, the Tracking and Data Relay Satellite System (TDRSS) in geosynchronous orbit, communications networks and computation centers for data processing, and strict safety and quality assurance controls.

"Astrophysics" is defined at NASA as the investigation of astronomical bodies by remote sensing from the Earth or its vicinity. This investigation is carried out by instruments aboard free-flying satellites, sounding rockets that penetrate into space for brief periods, high-flying aircraft and high-altitude balloons, and Space Shuttle missions. In general, the objects investigated by Astrophysics missions lie outside the Solar System and include stars, the interstellar medium (the tenous gas and dust between the stars), other objects in our Milky Way Galaxy, and galaxies beyond our own.

The study of the Sun falls within Space Physics, which deals with the near-space environment of the Earth and its response to the Sun. At NASA, the scientific study of the planets and other Solar System bodies is considered to be separate from Astrophysics because it is carried out predominantly by space probes to the bodies themselves rather than by remote sensing from the Earth or its vicinity. Earth science is a well developed field of its own; both life science and microgravity research are heavily dependent upon the manned-spaceflight program for research opportunities.

Science at NASA

Manned Spaceflight and Exploration:
- Space Shuttle
- Space Station
- Manned Exploration

Science:
- $\boxed{\text{Astrophysics}}$
- Space Physics
- Solar System
- Earth Science
- Life Science
- Microgravity

Advanced Technology:
- NASA Centers
- Universities
- Industry

Infrastructure:
- Expendable Launch Vehicles and Launch Facilities
- Communications and Data Processing
- Tracking and Data Relay
- Mission Safety and Quality Assurance

5. Vision and Guiding Principles

The Astrophysics Vision: To understand the origin, nature, and evolution of the Universe, we will lead the nation's efforts to carry out the best Astrophysics program possible for the available resources, we will share the knowledge gained with the public. Our decisions will be driven by our commitment to scientific excellence and will be made in an unbiased and open manner.

In pursuing this vision we will value:
Integrity, Honesty, Fairness, Respect, and Responsibility.

To pursue this vision, NASA's Astrophysics Division sponsors a broad range of flight programs that address fundamental questions in cosmology, astronomy, and physics by means of high-sensitivity, high-resolution observations across the electromagnetic spectrum.

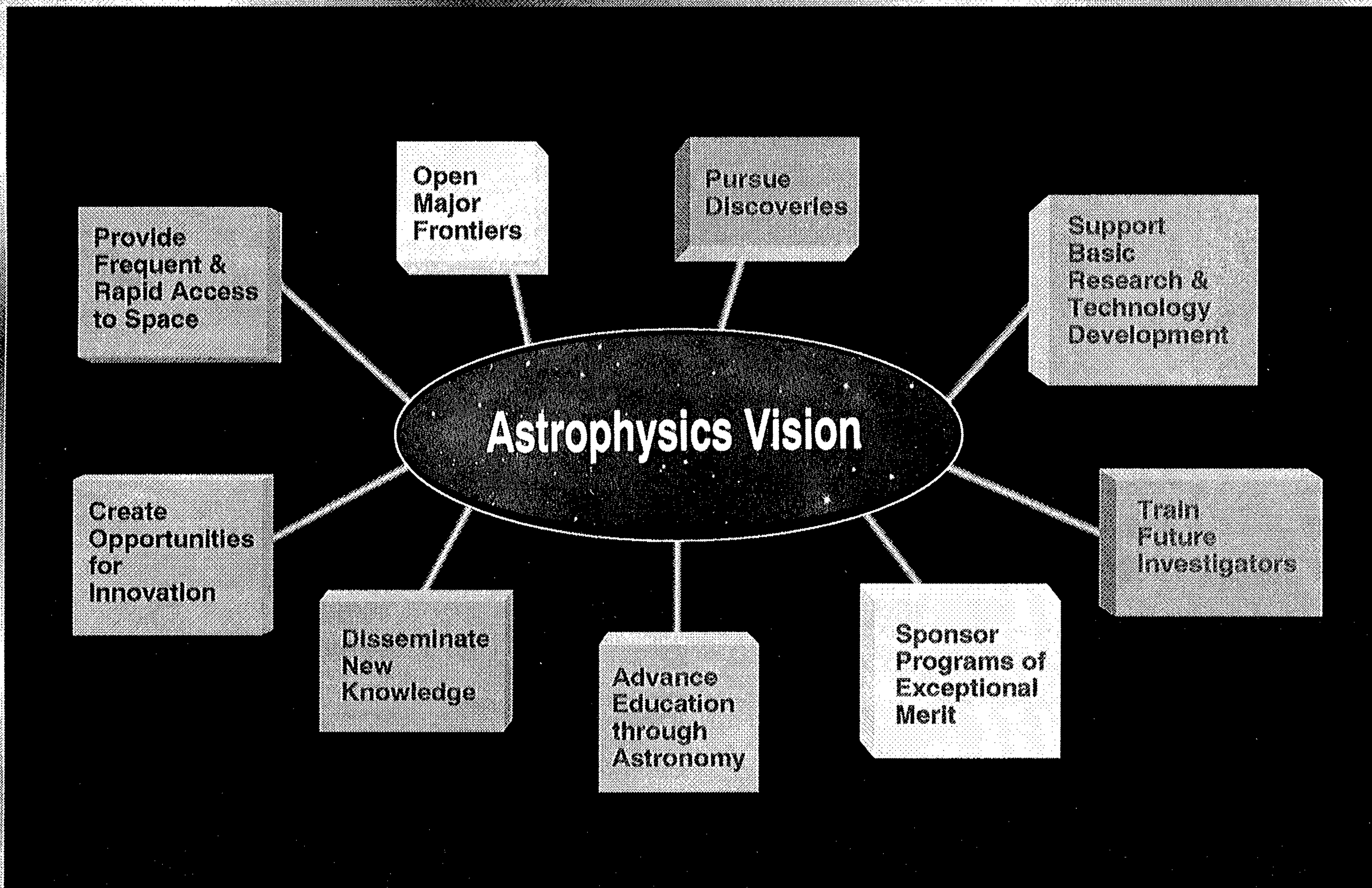
Advances in sensitivity (efficiency of light collection and detection) permit instruments to observe farther out in space and therefore farther back in cosmic time. Advances in temporal resolution (discrimination between signals arriving close together in time) aid the study of explosive "burst" sources of X rays and gamma rays and of such rapidly rotating objects as the neutron stars in pulsars or the disks of matter accreted by condensed stellar objects in binary systems. Advances in spectral resolution (distinction between adjacent colors or wavelengths of light) provide more accurate information about the temperature, chemical composition, surface pressure, and motion of an astronomical object.

In concert with the scientific community, the Astrophysics Division has also chosen nine basic principles to guide strategic planning and program development:

- Lead the opening of major scientific frontiers;
- Pursue discoveries with specialized follow-on missions;
- Provide frequent and rapid access to space;
- Create opportunities for innovation;
- Train the next generation of investigators;
- Advance national education goals using the unique appeal of astronomy;
- Invest in the future through basic research and technology;
- Produce, analyze, and disseminate new knowledge efficiently; and
- Sponsor scientific programs of exceptional merit.

For example, Astrophysics programs should lead the opening of scientific frontiers and disseminate new knowledge, as the Hubble Space Telescope and Compton Gamma Ray Observatory are currently doing. They should also provide frequent and rapid access to space, as the Small Explorer and suborbital programs are currently doing. They should support basic research and technology development and foster innovation, as the Research and Analysis Program, collaborative missions, and the Explorers are currently doing. And they should advance national education goals and help train future investigators, as the Initiative to Develop Education through Astronomy (IDEA) and suborbital programs are currently doing.

Vision and Guiding Principles



6. Formal Advisory Groups

The Astrophysics Division relies on the scientific community for expert advice and guidance, soliciting recommendations from formal advisory groups organized both by the National Academy of Sciences and by NASA.

NASA's Astrophysics Division develops its programs in close consultation with the scientific community at large. Advice external to NASA is provided through groups of outside scientists chartered by the U.S. National Academy of Sciences; advice internal to NASA is provided through groups of outside scientists chartered by the NASA Advisory Council.

The Academy's provision of advice to NASA is overseen by the Commission on Physical Sciences, Mathematics, and Astronomy, and by two of its boards: the Board on Physics and Astronomy, and the Space Studies Board. In response to requests from NASA, the Commission authorizes studies of space-science strategy carried out by the Space Studies Board through the Academy's operating arm, the National Research Council. A recently established Committee on Astronomy and Astrophysics (the CAA, successor to the earlier Committee on Space Astronomy and Astrophysics) will take responsibility for advising both NASA and the National Science Foundation on a continuing basis.

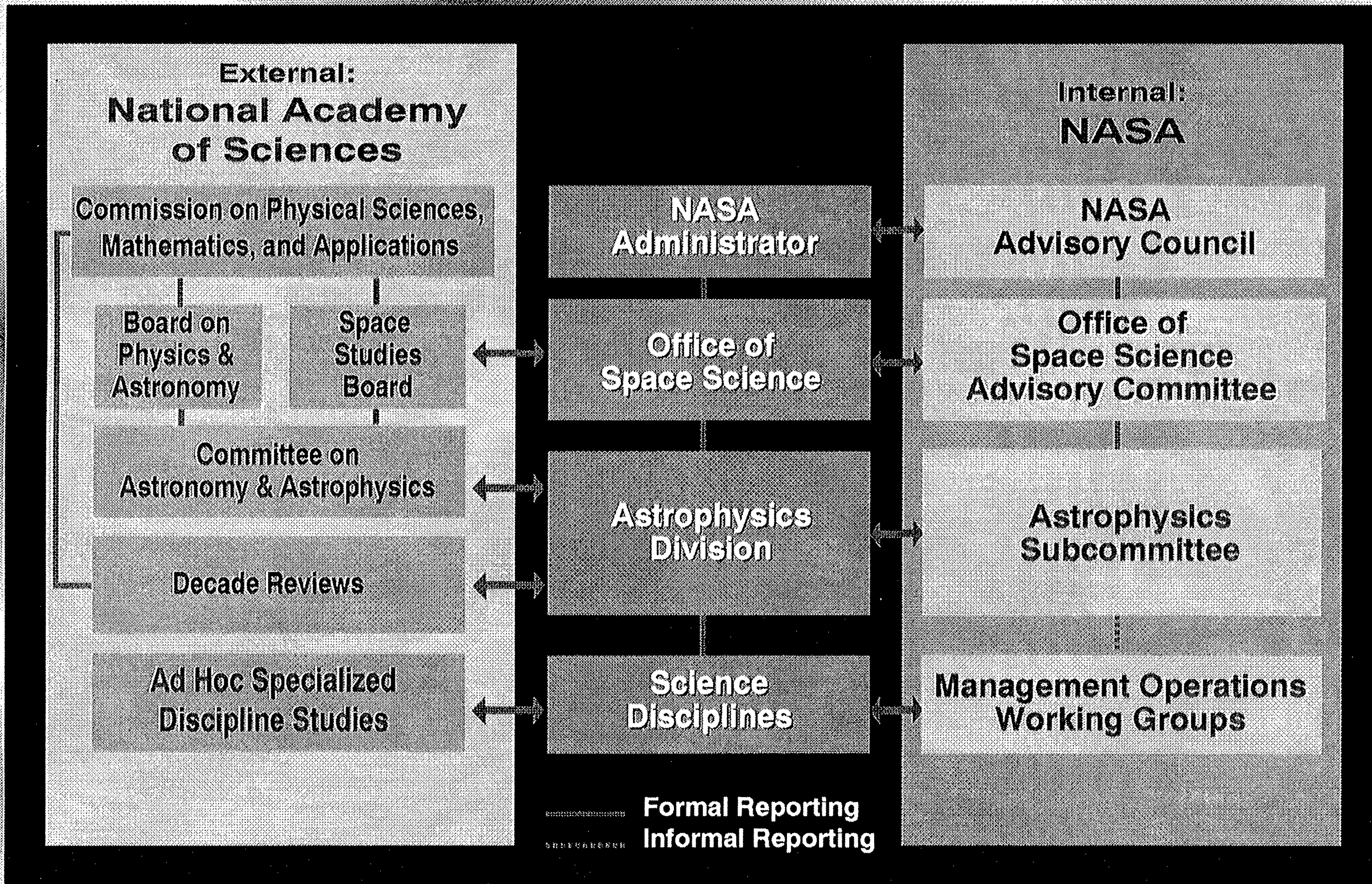
In addition, the Academy has carried out a comprehensive survey of research opportunities in astronomy and astrophysics each decade since the 1970s, presenting recommendations in priority order for both space and ground-based astronomy. (NASA cosponsors these decade studies together with the National Science Foundation, the Department of Energy, the U.S. Navy, and the Smithsonian Institution.) The most recent Astronomy and Astrophysics Survey Committee, which published its survey of research opportunities for the 1990s in March 1991, involved more than 300 of the nation's leading astronomers and astrophysicists. The work of the CAA and the decade reviews is supplemented by ad hoc, specialized discipline studies as appropriate.

NASA's internal advisory structure is headed by the NASA Advisory Council (NAC), which has a rotating membership of outside experts appointed by and reporting to the Administrator. At the next level, several programmatic committees, including the Office of Space Science Advisory Committee (OSSAC), provide advice to Associate Administrators of key program offices. At the lowest level, a family of subcommittees, including the Astrophysics Subcommittee, provides advice to Division Directors. Recommendations and issues may work their way up from subcommittee to committee to the full Council for deliberation and resolution.

The Astrophysics Subcommittee provides advice to the Astrophysics Division. Its members are leaders of the astronomical community, drawn from universities, government laboratories, and industry. The Subcommittee chairman serves as a member of the OSSAC and thus provides a direct communications link between the two groups. The Subcommittee also serves as a conduit for information from the astronomical community to the Division.

In addition, the Astrophysics Division sponsors Management Operations Working Groups (MOWGs) for each of its science branches: High Energy Astrophysics; Ultraviolet, Visible, and Gravity Astrophysics; and Infrared and Radio Astrophysics. It also sponsors MOWGs for Science Operations and Lunar Astrophysics. These groups of outside experts do not formally advise the Division but provide Branch chiefs with the perspective of the astronomical community on the operational aspects of their programs. MOWG chairmen are appointed members of the Astrophysics Subcommittee in order to provide direct communications links between the MOWGs and the Subcommittee.

Formal Advisory Groups



7. Program Development: Phased Life Cycle

The Astrophysics Division stresses a systematic, end-to-end, phased mission-development process that identifies and controls the life-cycle costs of a mission, while simultaneously ensuring the optimal meeting of scientific requirements.

Astrophysics programs follow the NASA Office of Space Science phased approach to program development. This approach proceeds through five phases (A, B, C/D, and E) ranging from strategic planning and concept studies to Mission Operations and Data Analysis.

This process begins with Astrophysics Division reviews of new mission concepts proposed by external and internal researchers and selection of the most promising proposals for concept (pre-Phase A) studies. Study results are subjected to internal and external review before the Division decides which concepts are worthy of feasibility studies (Phase A). An important component of these pre-mission and feasibility studies is the Supporting Research and Technology (SR&T) program, which supports laboratory astrophysics, theoretical astrophysics, and the testing of instruments through suborbital flights aboard rockets, balloons, and aircraft. The results of these investigations help to identify the optimum optical systems, radiation detectors, observing techniques, and data-gathering strategies for future missions.

Feasibility (Phase A) studies are intended to determine whether proposed mission concepts and technical objectives can be accomplished and are worthy of further definition. Feasibility-study results typically detail a single mission concept and alternative system design concepts that are suitable for definition studies (Phase B) and technology requirements.

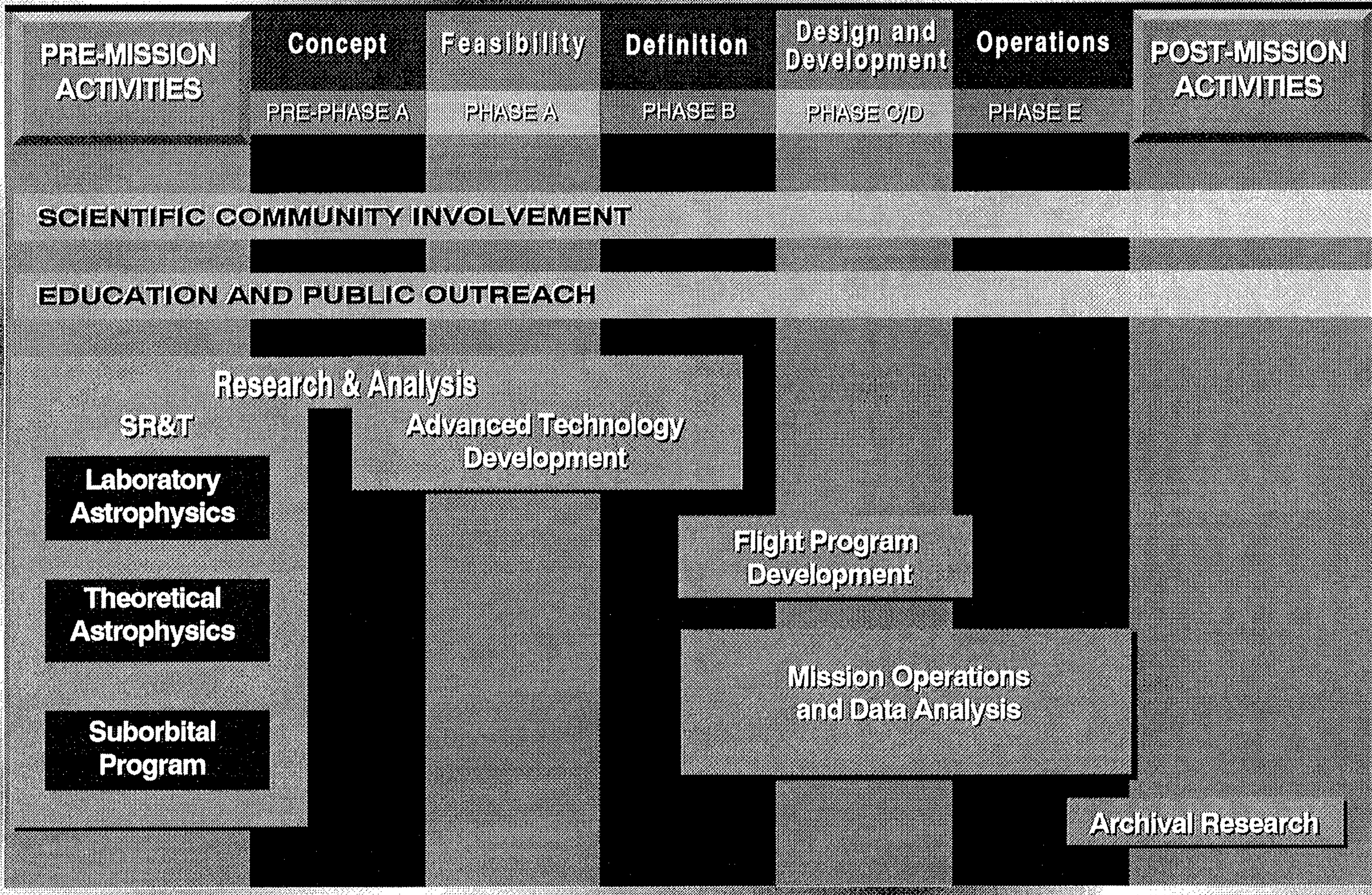
Mission definition (Phase B) marks a provisional intent to pursue a mission. At this point, the Division may distribute an Announcement of Opportunity (AO) for science investigations. Technology-development programs are conducted in this phase. The products of the definition phase include specific scientific objectives, preliminary technical specifications, schedules, resource requirements, and management plans.

If mission-definition studies indicate a mission is worth pursuing and if funding is approved, design and development begins (Phase C/D). This phase encompasses detailed implementation planning, hardware design and development, spacecraft and instrument integration and testing, support facility development, and launch and on-orbit checkout.

The Mission Operations & Data Analysis phase (MO&DA, Phase E) officially begins 30 days after launch. Mission operations can extend from one year, as in the case of the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX), up to 15 years, as with the Hubble Space Telescope (HST). Extending mission operations and expanding post-mission activities may depend on the performance of a mission, its scientific potential, and the availability of funds approved for mission operations and data analysis.

The science community plays a role in all the phases of Astrophysics program development, providing advisors, investigators, and the peer review of proposals for research. To reap the full benefits of its programs, the Astrophysics Division also conducts mission-related education and public-outreach activities throughout all phases of development.

Program Development: Phased Life Cycle



8. SR&T: Laboratory and Theoretical Astrophysics

Laboratory and theoretical astrophysics, funded through the Supporting Research and Technology (SR&T) program, are a low-cost, high-yield channel of investment in the future. They are also a precondition for the opening of new scientific frontiers.

Understanding the Universe requires the interplay of observation, laboratory research, and astrophysical theory. Efficient planning and thorough interpretation of astronomical observations requires a comprehensive and up-to-date base of empirical data and theoretical findings. These essential investigations are carried out predominantly at universities.

Research in laboratory astrophysics covers a broad range of topics, such as analysis of the colors of light absorbed or emitted by atoms and molecules (spectroscopy) and the interactions of atoms and molecules with each other (e.g., collisions). These studies are critical to interpreting astronomical observations and planning future missions, especially as the capability for high-resolution, high-sensitivity spectroscopy grows.

Theoretical investigations address such important questions as the origin of the predominance of matter over antimatter in the Universe and the evolution of large-scale structure in the Universe. Computer simulations are playing a growing role in theoretical studies of the physics underlying violent, complicated, and quickly evolving astrophysical phenomena.

For example, laboratory and theoretical studies of a family of complex molecules called Polycyclic Aromatic Hydrocarbons (PAHs) have led to a breakthrough in identifying features in the near- and mid-infrared spectra of a variety of astronomical objects and provided a clearer picture of carbon distribution in the interstellar medium and the likely mechanism of dust formation.

With a good working knowledge of current theory as well as current developments in laboratory research, astrophysicists can better interpret what they see. Observations may determine the physical characteristics of objects and processes. Investigators may then theoretically reconstruct the physical processes that cause the observed characteristics and test theories with further observations. Thus theory predicts what observations may reveal; new observing instruments take shape according to theoretical predictions of what might be seen; and theory is used to interpret observations, establishing a continuous, cyclic path toward eventual understanding.

SR&T: Laboratory & Theoretical Astrophysics

Laboratory Astrophysics

- Measurement of molecular, atomic, and nuclear processes
- Empirical study of bulk-matter physics and chemistry
- Experimental investigation of astrophysical processes

Theoretical Astrophysics

- Calculation of molecular, atomic, and nuclear properties
- Modeling of astrophysical systems
- Computer simulation of astrophysical processes

Mission Planning and Design

Interpretation of Mission Data

Tests of Astrophysical Theories

9. Suborbital Program

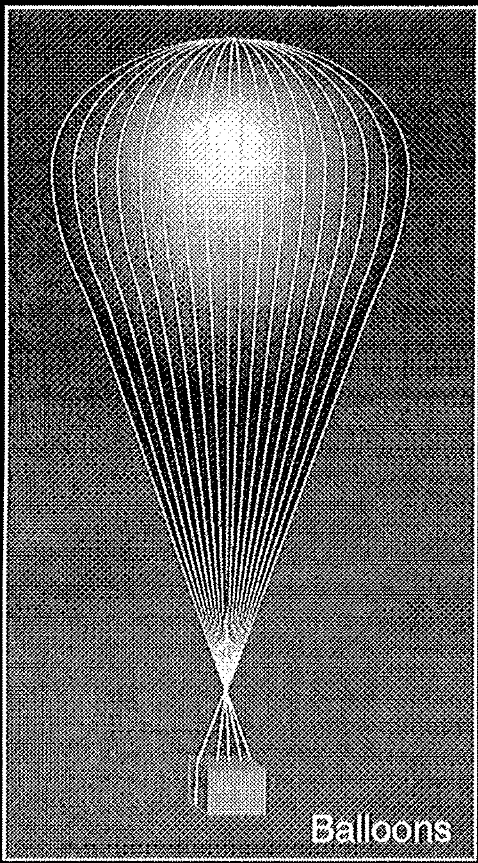
The Astrophysics Division's Suborbital Program sponsors instrument development and data research and analysis for small-scale, low-cost investigations launched on aircraft, balloons, and sounding rockets.

By spurring the invention and demonstration of new kinds of instruments, the Suborbital Program provides a vital technical foundation for the Division's larger Explorer and Great Observatory missions. Moreover, suborbital investigations provide rapid access to space for missions of opportunity—for example, observation of a newly discovered supernova, a solar eclipse, or a comet encounter. They also enable teachers, students, and young scientists to gain experience in space-based research. Most of this work is carried out at universities.

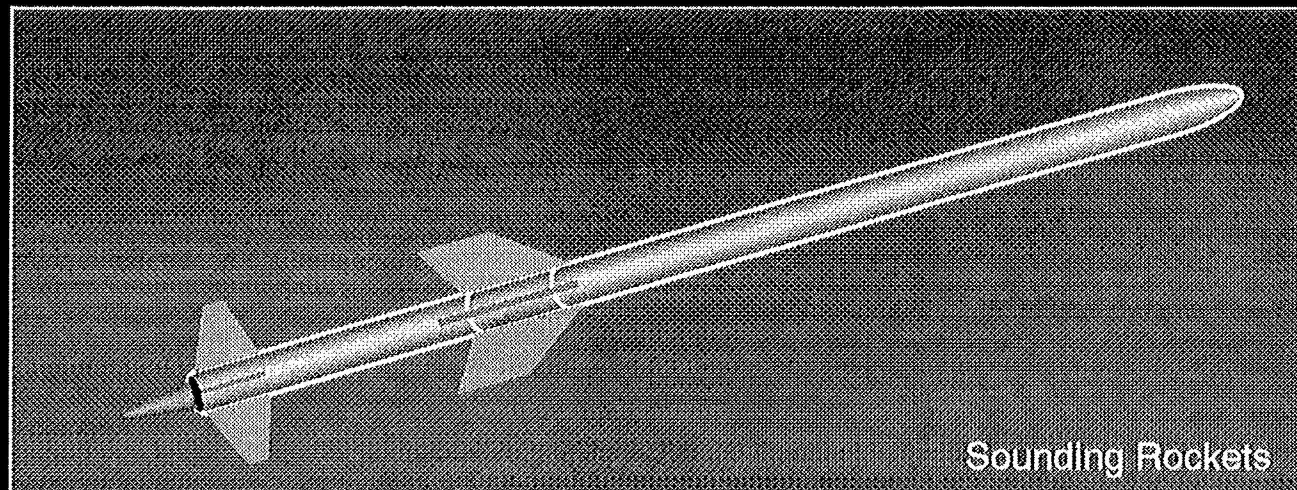
NASA's primary platform for airborne investigations is the Kuiper Airborne Observatory (KAO), a C-141 aircraft outfitted with an infrared telescope. Among the many scientific achievements of this highly mobile and versatile platform is the 1977 discovery of rings around the planet Uranus. The KAO program also serves as an avenue for the development of state-of-the-art instrumentation for infrared observations and for the education of science teachers. This program has been so effective that a larger and even more capable successor, the Boeing 747-based Stratospheric Observatory for Infrared Astronomy (SOFIA), is being proposed to continue such research into the next century.

Sounding rockets and balloons provide rapid access to space for ultraviolet, X-ray, and gamma-ray observations that cannot be done on the ground. Sounding rockets opened up the fields of X-ray and ultraviolet astronomy through pioneering, 5-minute flights in the 1960s; these vehicles remain of great value for the development of space-qualified instruments for ultraviolet observations. High-altitude balloons have long proved their worth for observations of infrared radiation and gamma rays of very high energy; now that two-week flights have become technically feasible, balloons offer expanded promise for observations of high-energy "hard" X rays that only penetrate the outer layers of the atmosphere. NASA's sounding-rocket and balloon programs are managed by the Space Physics Division.

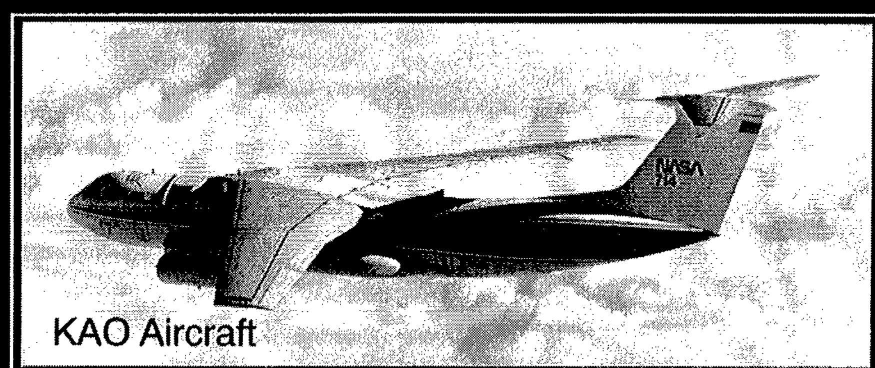
Suborbital Program



- Moderate cost
- Heavy payloads
- Long duration
- Optimum for gamma-ray and infrared research



- Low cost
- Flexible launch schedule
- Rapid instrument development
- Optimum for ultraviolet and X-ray research



- Large payloads
- Frequent flights
- Variety of auxiliary instruments
- Optimum for infrared and submillimeter research

10. Advanced Technology Development

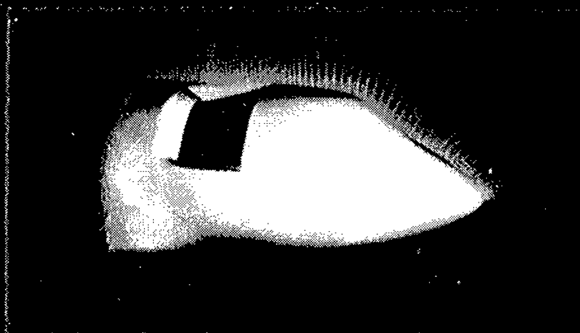
The definition and development of advanced technology is the key to a vigorous program and a productive future in space science. The Astrophysics Division funds Advanced Technology Development (ATD) through the Supporting Research and Technology (SR&T) Program.

The primary goal of the Advanced Technology Development (ATD) program is the preparation of new astrophysics mission concepts and technology for development. The program has two components: mission definition and technology development. A primary aim of both these components is the identification and study of life-cycle costs as input information to the phased mission-development process.

The first ATD component proceeds through the concept (pre-Phase A), feasibility (Phase A), and definition (Phase B) studies, including risk assessment, cost identification, and the identification of technology requirements. This kind of groundwork permits the Astrophysics Division to employ a fixed-cost program management philosophy. Current Astrophysics concept and feasibility studies include the Stratospheric Observatory for Infrared Astronomy (SOFIA), the Space Infrared Telescope Facility (SIRTF), the International Gamma Ray Astrophysical Laboratory (INTEGRAL), the Submillimeter Intermediate Mission/Far Infrared Space Telescope (SMIM/FIRST), and the Astrometric Interferometry Mission (AIM).

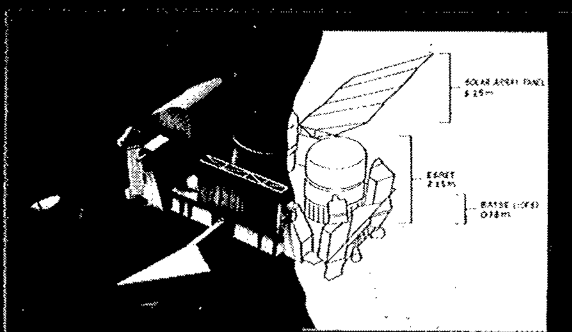
Advanced technology development activities proceed in line with requirements established by mission definition studies. Current Astrophysics technology development activities include infrared technology for SIRTF and submillimeter technology for SOFIA. In addition, the Division is jointly funding ATD with the Office of Advanced Concepts and Technology (OACT) for SMIM and optical/ultraviolet interferometry.

Advanced Technology Development



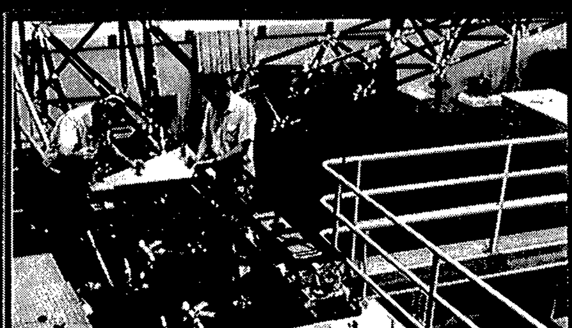
- Investigate alternative mission concepts
- Fly new technology on every mission
- Enforce consistency with Vision and Guiding Principles

Mission Feasibility and Concept Studies



- Define requirements for instruments and spacecraft
- Develop mission plan: scope, schedule, budget
- Minimize life-cycle cost

Mission Definition



- Achieve order-of-magnitude improvement in instrument performance
- Optimize spacecraft systems
- Facilitate data acquisition and processing

Technology Development

Optimal Mission Design

Outstanding Mission Performance and Favorable Benefit/Cost Ratio

New Capabilities and Major Increase in Scientific Return

11. Flight Program Management

NASA management of flight programs involves a balance of responsibilities between the program office (at NASA Headquarters) and the corresponding project office (at a NASA field center). The Program Manager at NASA Headquarters is responsible for making the tradeoffs in program performance that may be required to control cost and maintain schedule.

The management of an Astrophysics flight program is a team effort. The key players at NASA Headquarters (the "program level") are the Program Scientist and the Program Manager, who work together with other Headquarters personnel on mission planning and management. The key players at the NASA field center responsible for carrying out the mission (the "project level") are the Project Scientist and the Project manager, who work closely with center personnel and with their Headquarters counterparts.

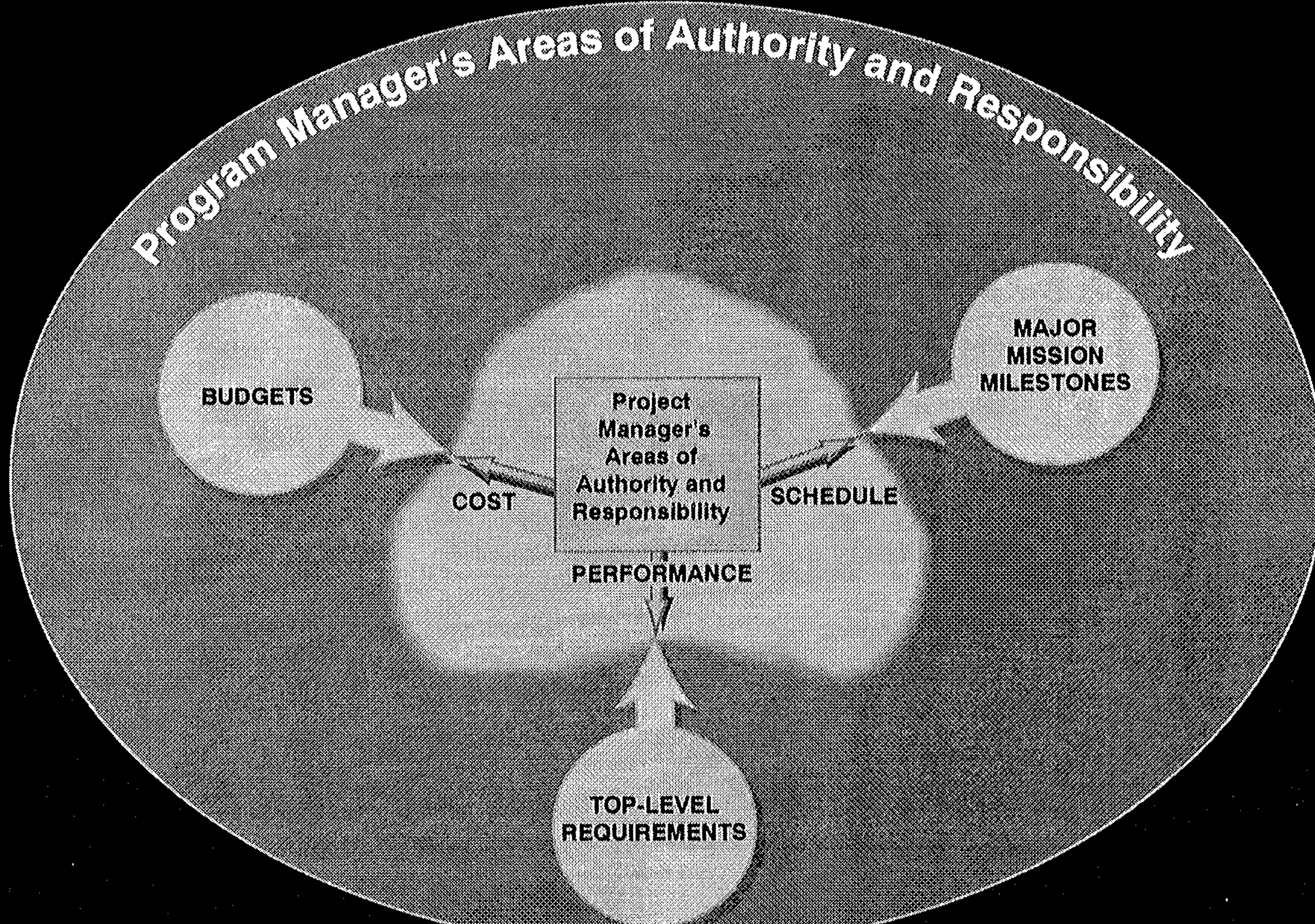
This splitting of management responsibilities between program and project is a unique aspect of NASA organizational culture, and it provides the checks and balances that ensure successful implementation of the program. However, it is ultimately the Program Manager who must see to it that the program is completed on schedule and within budget.

During both concept (pre-Phase A) and feasibility (Phase A) studies, the Program Scientist within the Astrophysics Division works with the Program Manager, the astrophysics community, and their counterparts at NASA field centers to define science goals and requirements for new flight programs. Through definition (Phase B) and design and development (Phase C/D) activities, the Program Scientist defines and monitors top-level science requirements and science policy, prepares Announcements of Opportunity (AOs) for science investigations, formulates science operation plans, and develops Guest Investigator programs. In the initial phases of the program, the Program Manager is responsible for top-level mission planning, management policy definition, and ensuring that the scientific scope of the mission is consistent with schedule and budget.

During design and development (Phase C/D) of a flight program, the focus of activities shifts from NASA Headquarters to a NASA field center, where the mission is actually carried out. There, a Project Scientist is responsible for forming and chairing a Science Working Group to translate top-level scientific guidance into detailed science requirements and policy, and for otherwise guiding project scientific efforts. The Project Manager is responsible for achieving agreements among participating organizations, and for translating top-level management guidance into detailed mission requirements, program funding requirements, and management policies. The Project Manager develops a project (implemention) plan, maintains a detailed budget and schedule, and oversees day-to-day project work.

NASA strives to foster close coordination and policy agreement between the program office and the project office. However, if it becomes clear that the original performance objectives cannot be met within the current cost and schedule, the Program Manager has both the authority and responsibility to make the tradeoffs of performance against cost and schedule that may be necessary to keep the program within budget and meet major mission milestones.

Flight Program Management



12. Mission Types

The Astrophysics Division sponsors observations carried out through four types of missions: free flying, suborbital, Shuttle-attached, and collaborative.

In terms of space-hardware design and function, there are basically three mission categories: free-flying satellites, suborbital missions, and payloads attached to the Space Shuttle. Missions involving the collaboration of NASA with an external organization may make use of any of these three hardware approaches; however, because collaborative missions have special programmatic aspects, they are often considered a fourth mission type.

Free-flying spacecraft are those that operate in Earth orbit independently of any other platforms. These missions range from large-scale and long-term, such as the Great Observatories (e.g., Hubble Space Telescope), down to small- and medium-sized Explorers (e.g., the Extreme Ultraviolet Explorer). This category may also include intermediate-class missions (e.g., Gravity Probe-B). Free-flyers offer the advantages of extensive operating lifetimes, spacecraft tailored to the mission in question, and a choice of orbit.

Suborbital missions include payloads flown on high-altitude balloons and sounding rockets and on specially modified high-altitude aircraft, such as NASA's current Kuiper Airborne Observatory and, in the future, the proposed Stratospheric Observatory for Infrared Astronomy (SOFIA). These missions offer rapid, low-cost access to space and are highly valuable for testing new technology and training young investigators.

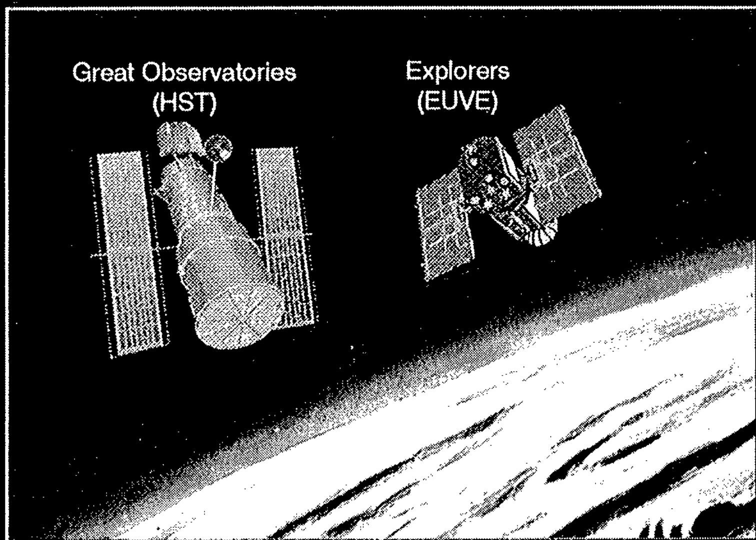
Shuttle-attached payloads are flown in the Space Shuttle's cargo bay and exposed to space for periods lasting up to a week or so. They include "Get Away Special" experiments contained in cannisters ("GAS cans") and instruments installed on Spacelab pallets. Among the Shuttle payloads sponsored by the Astrophysics Division is the ASTRO complement of three ultraviolet telescopes, which flew in December 1990 (ASTRO-1) and is currently scheduled for reflight in 1994 (ASTRO-2). The Shuttle is also capable of deploying instrument-bearing observing platforms for periods of 6 months or more, then retrieving them for return to Earth.

Collaborative missions are international or interagency partnerships, which may involve a wide range of contributions from the different partners. A representative sampling of current collaborative missions includes the Hubble Space Telescope (HST), the Roentgen Satellite (ROSAT), ASTRO-D, and the Array of Low-Energy X-Ray Imaging Sensors (ALEXIS).

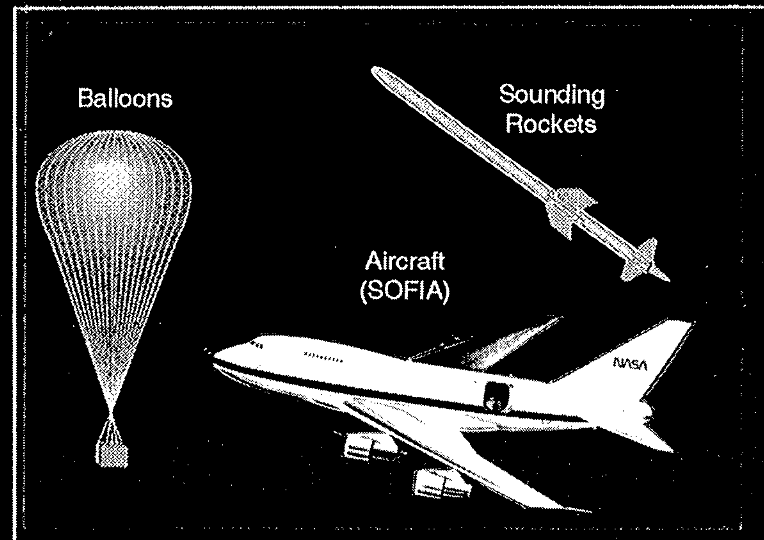
HST, launched in 1990, is a partnership between NASA and the European Space Agency (ESA), which contributed the HST solar arrays and one of six scientific instruments (the Faint Object Camera) in return for access to HST data. (ESA will also contribute the replacement solar arrays to be installed on the first HST servicing mission.)

The X-ray satellite ROSAT, also launched in 1990, is primarily a German mission, but NASA contributed a high-resolution imager for the telescope focal plane and a Delta launch, and the British contributed a telescope for extreme-ultraviolet observations. The Japanese X-ray satellite ASTRO-D, launched in February 1993, incorporated metal-foil mirrors and two focal-plane detectors provided by NASA. The small ALEXIS X-ray mission, scheduled for launch in the spring of 1993, is sponsored primarily by the U.S. Air Force and the Department of Energy, but NASA is also participating in return for data access.

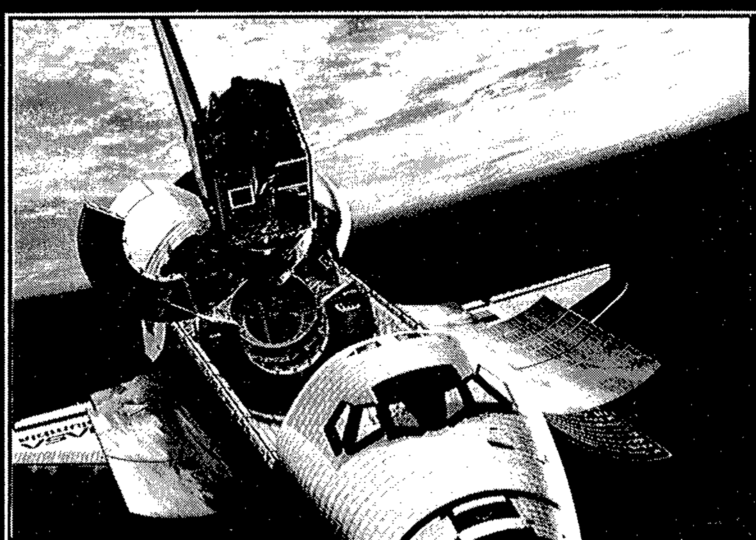
Mission Types



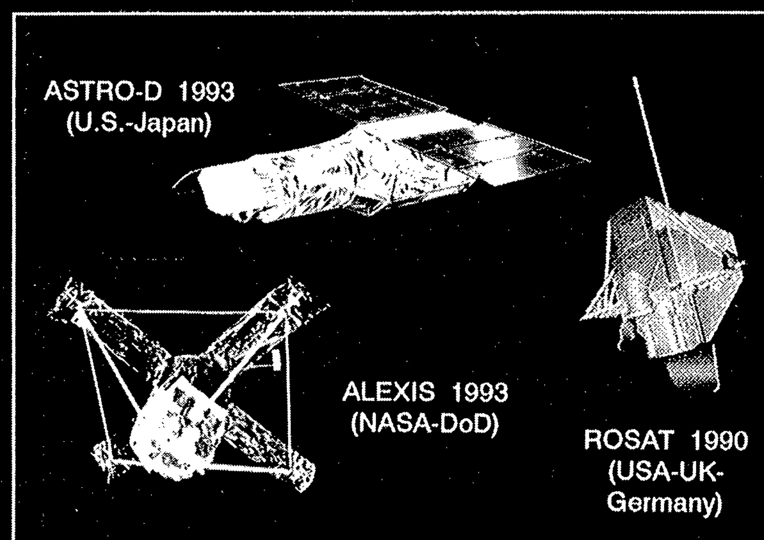
Free Flyers



Suborbital Program



Shuttle-Attached Payloads



Collaborative Missions

13. The Great Observatories

The Great Observatories are the centerpiece of the Astrophysics Program.

The Great Observatories are:

- Hubble Space Telescope (HST), launched in 1990;
- Compton Gamma Ray Observatory (CGRO), launched in 1991;
- Advanced X-Ray Astrophysics Facility (AXAF), planned for launch in 1998-1999; and
- Space Infrared Telescope Facility (SIRTF), now under study for initiation in 1996 and launch around the turn of the century.

Together, these four observatories will span the electromagnetic spectrum from high-energy, gamma-ray wavelengths to low-energy, infrared wavelengths, carrying out long-term observations within four important spectral regions.

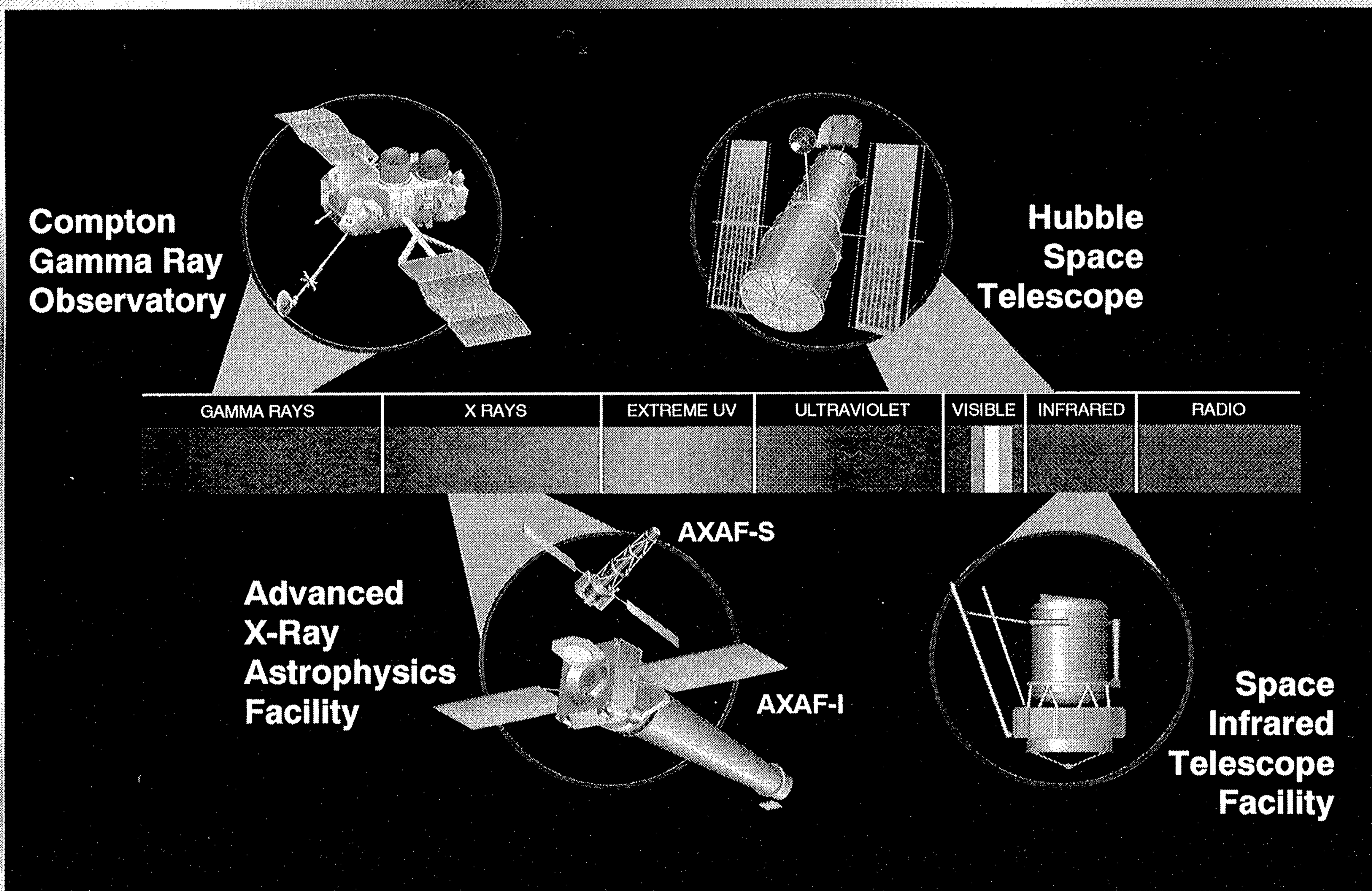
HST, now conducting observations in the visible and ultraviolet spectral regions, is nearing completion of its third productive year of operation as a world-class observatory. Software fixes have partially compensated for flaws in the HST primary mirror and solar arrays; corrective optics, redesigned solar arrays, and other items to replenish redundancy (e.g., gyroscopes, computer coprocessors) will be installed on the first Space Shuttle servicing mission scheduled for late 1993. Observational breakthroughs recorded to date include the discovery of stellar regeneration in old star clusters, new evidence for black holes at the center of several galaxies, and imaging of protoplanetary disks around some nearby stars.

CGRO is investigating the most energetic systems and violent events in the Universe. Observations have produced evidence that the mysterious gamma-ray bursts seen by earlier satellites are distributed evenly across the sky rather than concentrated toward the plane of the Milky Way Galaxy, as previously believed. This key finding is still unexplained.

In 1992, the AXAF program was restructured to reduce cost and schedule, bringing it in line with available resources while retaining most of its initially planned capabilities. Originally designed as a single large observatory, AXAF now will be launched as two separate missions: AXAF-Imaging, a high-spatial-resolution imaging mission, planned for launch into a high-Earth orbit in 1998; and AXAF-Spectroscopy, a high-resolution spectroscopy mission planned for launch into a low-Earth orbit in 1999.

SIRTF, a powerful infrared observatory that won the highest recommendation of the National Academy of Sciences' Astronomy and Astrophysics Survey Committee for space-based projects of the 1990s, has also recently undergone restructuring resulting in significant reduction of projected mass and cost. SIRTF is currently in concept (Phase A) study, with launch projected for the turn of the century. Major advances in sensor technology are nearly achieved, thereby preparing this mission for detailed definition activities.

The Great Observatories



14. The Explorer Program

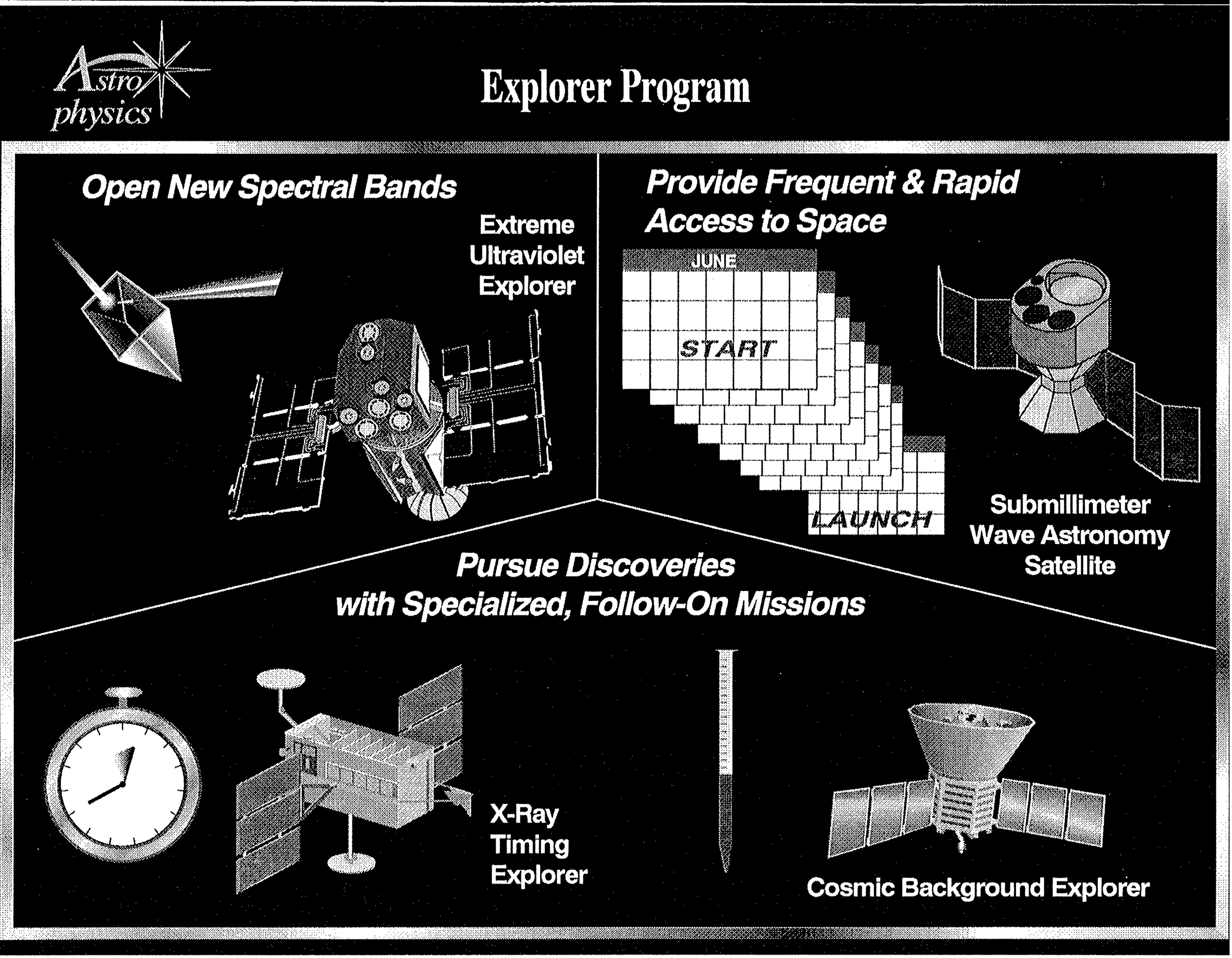
NASA's Explorer Program, begun in 1958, continues to provide opportunities for pioneering research and the pursuit of new discoveries. In 1991, the program was restructured to provide more frequent and rapid access to space.

NASA's Explorer Program is managed by the Astrophysics Division and currently supports both the Space Physics and Astrophysics Programs. Over the past decade, Astrophysics Explorers have been substantial missions intended for launch by highly capable Delta expendable launch vehicles; in the future, smaller missions also will be included to reduce the time between development and launch.

Delta-class Explorers currently in operation for Astrophysics observations include the Cosmic Background Explorer (COBE) and Extreme Ultraviolet Explorer (EUVE). Launched in 1989, COBE produced the data behind one of the major scientific discoveries of 1992: slight variations in the temperature of the cosmic microwave background radiation temperature that are believed to reflect structure present in the early Universe shortly after the Big Bang. EUVE, launched in 1992, has now completed an all-sky survey in the relatively unknown extreme-ultraviolet region of the spectrum and has begun detailed spectroscopic studies of individual sources. Delta-class Explorer missions now under development in the Astrophysics Program include the X-Ray Timing Explorer (launch 1996), the Advanced Composition Explorer (a Space Physics mission, launch 1997), and the Far Ultraviolet Spectroscopic Explorer (launch 2000).

In 1988, NASA created a new Small Explorer mission class designed to speed access to space. The first Small Explorer mission, the Solar, Anomalous and Magnetospheric Particle Explorer, was launched in 1992 after a development period of less than three years. Two more Small Explorers are under development: the Fast Auroral Snapshot Explorer (launch 1994) and the Submillimeter Wave Astronomy Satellite (launch 1995).

In 1991, the Astrophysics Division restructured the Explorer Program to phase out the Delta-class missions, which had grown larger and larger over the years. The planned future program has three components (costs given in FY 1993 dollars): Middle-Class Explorers (typical development cost, $65 to $70 million; first launch planned for 1999), Small Explorers (typical cost, $35 million), and University Explorers (typical cost, $30 million). The goal is to achieve one launch per year (in either Astrophysics or Space Physics) in each or these three Explorer categories.



Astro physics
Explorer Program
Open New Spectral Bands
Extreme
Ultraviolet
Explorer
Provide Frequent & Rapid
Access to Space
JUNE
START
LAUNCH
Submillimeter
Wave Astronomy
Satellite
Pursue Discoveries
with Specialized, Follow-On Missions
X-Ray
Timing
Explorer
Cosmic Background Explorer

15. Collaborative Missions

Partnerships with other nations or agencies provide cost sharing, make good use of unique national capabilities, and yield an increase in flight opportunities. The benefits are greater international understanding and an increase in knowledge for humanity.

Collaborations with other nations or with other U.S. federal agencies offer advantageous and cost-effective ways to amplify and supplement the scientific return from NASA's own Astrophysics program. Such ventures also can be crucial for research progress. During the long hiatus in X-ray observations from U.S. free-flying observatories, which began in 1981 and has extended into the 1990s, international missions provided almost the only sources of new X-ray data.

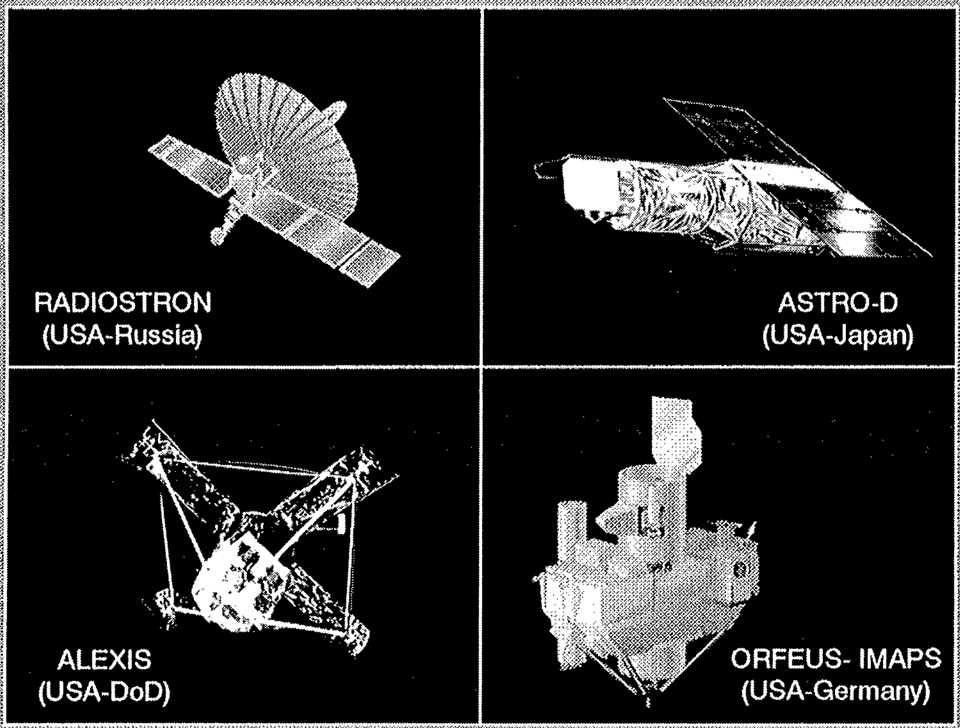
Numerous international collaborations are now under way or under discussion. Hubble Space Telescope is a collaboration between NASA and the European Space Agency (ESA). ASTRO-D, launched in February 1993, is a spectroscopic X-ray observatory developed by Japan's Institute of Space and Astronautical Science. NASA contributed mirror assemblies and charge-coupled device (CCD) detectors to the ASTRO-D science payload. Another collaborative mission with Japan is the Very Long Baseline Interferometry Space Observatory Program (VSOP), which is a Japanese orbiting very-long-baseline interferometer (VLBI), scheduled for launch in mid-1995. Both U.S. and Japanese ground-based radio-astronomy facilities will participate in the program and the U.S. will provide VSOP with Deep Space Network (DSN) tracking, data acquisition, orbit determination, and phase transfer.

The Astrophysics Division has several collaborations under way with the Russian Academy of Sciences. For example, NASA is collaborating with Russia on the Spectrum X-Gamma high-energy astrophysics mission targeted for launch in late 1995. The U.S. will furnish two instruments for Spectrum X-Gamma: The Monitoring X-Ray Experiment (MOXE) and the Stellar X-Ray Polarimeter (SXRP). A second joint project is Radioastron, a free-flying spacecraft that will operate as part of an extended-baseline VLBI for radio-astronomy observations. The U.S. will provide Radioastron with DSN support, four Very Long Baseline Array (VLBA) recording terminals, and observing time on the VLBA in return for correlation of selected data sets. Radioastron is planned for a 1997 launch.

Two additional projects represent a collaboration with Germany: the Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer (ORFEUS) and the Interstellar Medium Absorption Profile Spectrograph (IMAPS). These instruments, intended for ultraviolet observations of interstellar gas clouds, will be launched by the Space Shuttle in 1993 aboard the German-developed ASTROSPAS platform; the platform will be retrieved by the Shuttle after a week of observations and returned to the ground.

Ventures involving NASA and other federal agencies provide a second avenue for collaboration. One such mission is now imminent: ALEXIS (Array of Low-Energy X-Ray Imaging Sensors), scheduled for launch in 1993, is a joint endeavor of NASA, the Department of Energy, and the U.S. Air Force. ALEXIS will carry out a survey of ultra-soft X-ray sources across the sky and monitor these sources for variability.

Collaborative Missions



Cost Sharing

Greater International Understanding

Use of Unique National Capabilities

Increase in Flight Opportunities

Increase in Knowledge for Humanity

16. Gravity Probe-B

Einstein's General Theory of Relativity is a cornerstone of modern cosmology, yet this theory is nearly untested. Gravity Probe-B will carry out a new, fundamental test from space—and blaze new trails in advanced technology.

In 1905, the 25-year-old Albert Einstein formulated the Special Theory of Relativity, the first physical theory to postulate a connection between space and time. Its predictions—for example, the famous formula $E = mc^2$—have been confirmed to high accuracy by experiments over the past 85 years.

But the Special Theory suffered from an important restriction: it was not clear how to apply it to the force of gravity. In a great intellectual leap, Einstein later generalized the concept of mixing space and time to formulate the General Theory of Relativity (1916). The General Theory provides a mathematical formalism for calculating the warping effect of gravity on space-time. If an observer is freely falling in a gravitational field, the effects of gravity disappear, and the General Theory reduces to the Special Theory in the region of the observer.

However, the predictions of General Relativity—essentially a theory of gravitation—have not been tested outside the weak, static gravitational fields of our Solar System. Even NASA's 1976 Gravity Probe-A rocket flight, which carried a highly accurate clock high above the Earth's surface and verified the predicted slowing down of the clock rate to 1 part in 1,000, was not a test of the curvature of space; rather, it confirmed the conservation of energy in a gravitational field.

There are, in addition, troubling suspicions that the theory is fundamentally flawed. The other three forces in nature—electromagnetism and the strong and weak nuclear forces—can be described by quantum mechanics; however, General Relativity has defied all attempts at a quantum reformulation. As a result, astrophysicists have not been able to apply relativity theory to models of the creation of the Universe, when the curvature of space was high and the Universe was presumably of atomic dimensions. Despite these nagging problems, General Relativity continues to be broadly applied in astrophysics not only to describe the expansion of the Universe but also the radiation of gravitational waves and even the bizarre properties of black holes.

Gravity Probe-B (GP-B) will measure a completely different mixing of space and time than has been measured before: the rotation of empty space in response to the rotation of a massive body. The effect specifically predicted by the General Theory is called "frame dragging." Because rotational effects predicted by other physical theories in this century have repeatedly been proven wrong, the frame-dragging measurement is accorded very high scientific importance. First conceived three decades ago, GP-B will draw upon the accumulated advances in technology that now permit the extraordinarily minute frame-dragging effect of the Earth to be accurately measured. Moreover, GP-B will measure the curvature of space to 1 part in 10,000—by far the most sensitive test of the theory ever carried out.

Although other relativity experiments have essentially confirmed Einstein's basic assumptions and points of mathematical departure, GP-B will test the validity of Einstein's field equations themselves in a domain never before investigated. In this sense, GP-B will carry out the first fundamental test of General Relativity, and by far the most challenging to date.

Gravity Probe-B

17. Future of Infrared Research

Two NASA missions are vital to the future of infrared research: the Space Infrared Telescope Facility (SIRTF) and the Stratospheric Observatory for Infrared Astronomy (SOFIA), both targeted to begin operation at the end of the decade.

The last major infrared-astronomy space mission was the Infrared Astronomical Satellite (IRAS), a joint U.S.-Dutch program that operated from 1983 until 1985. Despite the enormous productivity of IRAS, no NASA infrared-astronomy mission has since been approved. Moreover, the 18-year-old Kuiper Airborne Observatory (KAO) is beginning to approach the end of a productive lifetime. It is now essential to follow both IRAS and KAO with facilities that will continue forefront infrared research into the next century: SIRTF and SOFIA.

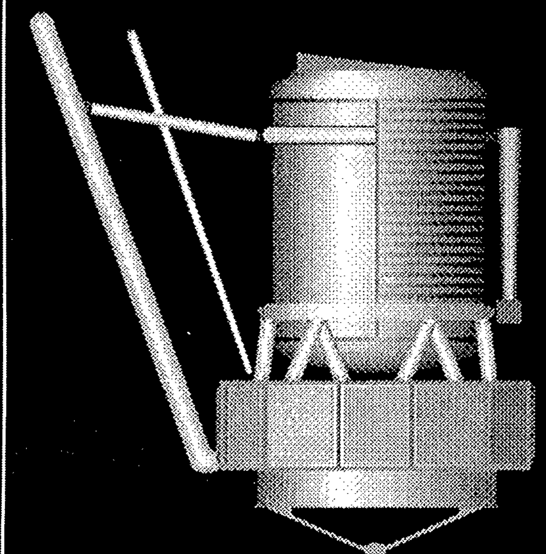
From its orbital vantage point above the Earth's radiation belts, what SIRTF will do best is observe very faint objects—for example, distant young galaxies at the edge of the Universe, or planets in the process of formation around other stars. This facility, the infrared element of the "Great Observatories" program, will permit continuous, highly efficient observations over a three-year mission lifetime. The Astrophysics Division adopted a new SIRTF configuration in 1992, and Phase-A studies are in progress. The National Academy of Sciences' Astronomy and Astrophysics Survey Committee for the 1990s identified SIRTF as the top-priority major new U.S. space-astronomy mission for the 1990s. Its launch would complete the deployment of all four of NASA's Great Observatories in space.

The Boeing 747-based SOFIA, outfitted with a 2.5-meter telescope, will support detailed studies of star and planet formation, the dynamics and chemistry of the interstellar medium, and the structure and evolution of the solar atmosphere, other solar-system bodies, our Milky Way galaxy, and other galaxies. Frequent flight opportunities and rapid turnaround over SOFIA's 20-year operational lifetime will permit airborne astronomers to continually push the state of the art in infrared-instrument technology. SOFIA also will be ideally suited for launching investigations of such transient events as eclipses, occultations, comets, novae, and supernovae on short notice. Moreover, the observatory will serve as a goodwill ambassador for NASA throughout the U.S.A. and the rest of the world, and it will stimulate interest in astronomy among the public and students at all levels. With definition (Phase B) studies completed, SOFIA is ready for design and development (Phase C).

Although researchers are still plumbing the IRAS data archive, one must recall again that the pioneering IRAS satellite ceased operation in 1985 and that there has been no U.S. successor, although an infrared mission sponsored by the European Space Agency, the Infrared Space Observatory (ISO), is scheduled for launch in 1995. Meanwhile, KAO has been flying since 1975 and is becoming increasingly difficult to maintain operationally. The cumulative astrophysics data base is anticipated to grow considerably in the ultraviolet, visible, and high-energy spectral bands over the next 10 years because of the observations of approved missions; by contrast, most of the data growth in the infrared band (apart from ISO data) is projected to come from SIRTF and SOFIA, which are not yet approved. If these missions are not initiated as planned, progress in infrared astronomy will therefore lag behind advances in other spectral bands.

Astro physics

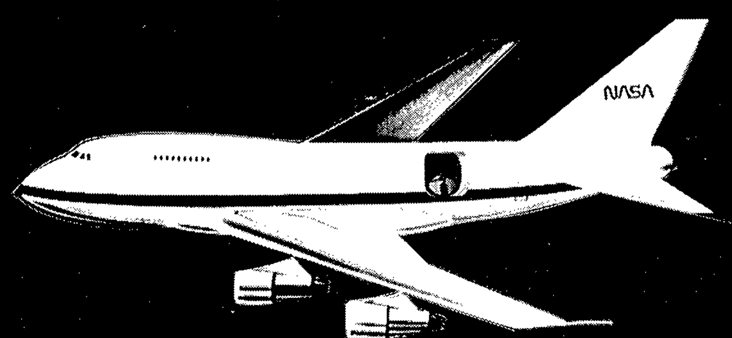
Future of Infrared Research



Space Infrared Telescope Facility

SIRTF

- Optimized for study of very faint objects -- e.g., young galaxies at the edge of the Universe
- Could detect planets forming around nearby stars
- Provides continuous observations over 3-year mission lifetime



Stratospheric Observatory for Infrared Astronomy

SOFIA

- Optimized for study of star and planet formation, dynamics and chemistry of the interstellar medium, galactic structure
- Permits rapid response to transient events -- eclipses, occultations, supernovae
- About 160 flights per year over a 20-year lifetime
- Stimulate interest among public and students
- World-wide goodwill ambassador for NASA/U.S.

18. Mission Operations & Data Analysis

Mission Operations & Data Analysis (MO&DA) supports the analysis and interpretation of astrophysical data, which generates the scientific return on NASA's current and future investments in flight missions. Continued investments in data-handling technology will be needed to keep pace with future increases in data volumes.

NASA's space-astronomy program has produced major breakthroughs in knowledge over the past three decades—advances made possible by investments in (1) mission operations, necessary to obtain the data returned by the missions; and (2) data reduction and analysis, necessary to give meaning to the data. These vital functions are funded through the Astrophysics Division's Mission Operations & Data Analysis (MO&DA) program. Support is provided to Guest Investigator (GI) and Guest Observer (GO) programs as well as to related data-analysis activities, including astrophysical theory, archival research, and multispectral analyses.

By comparison with the early years of space astronomy, today's Astrophysics Division research program is much more data-intensive because extraction of information from the data has become much more complex. Missions now typically carry multiple instruments; rates of data acquisition are higher, and mission lifetimes are longer. Data volumes are therefore vastly greater than those of even a decade ago. However, only detailed analyses of observational data, coupled with interpretations provided by astrophysical theory, can yield real advances in our understanding of the Universe.

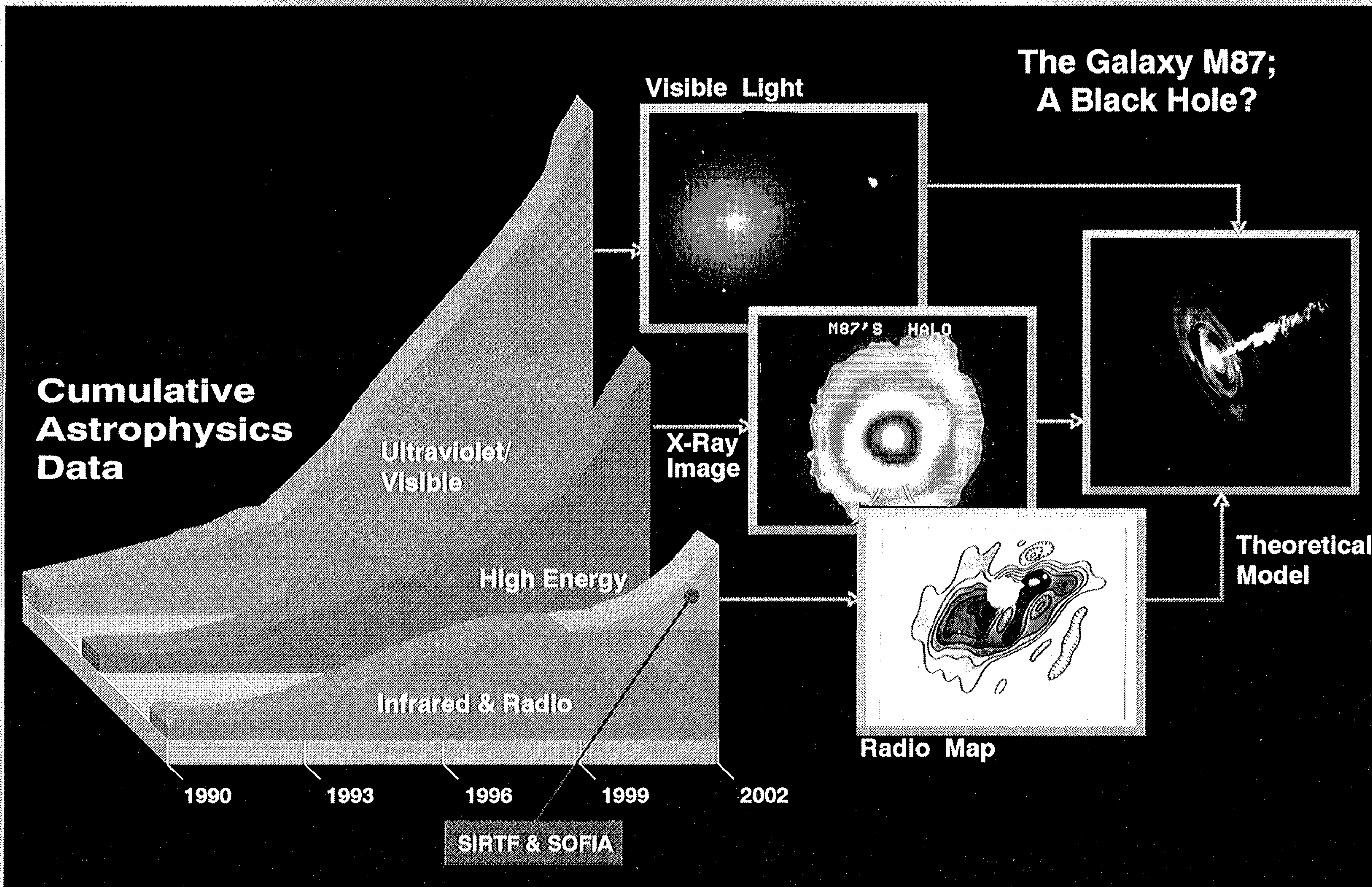
Recently launched astrophysics missions are now bearing fruit in the form of substantial new data streams. Data volumes in the ultraviolet and visible spectral bands, for example, are rising rapidly because of observations returned by the Hubble Space Telescope (1990) and the Extreme Ultraviolet Explorer (1992); the International Ultraviolet Explorer (1978) continues to return data as well. Data volumes in the high-energy spectral region are increasing because of observations by the Roentgen Satellite (1990) and the Compton Gamma Ray Observatory (1991); an additional boost will be provided by ASTRO-D (1993) and the Advanced X-Ray Astrophysics Facility (end of the decade).

Such new data, which represent the culmination of years of previous development efforts, hold the promise for immense new contributions to knowledge. And data volumes are expected to continue to grow. The potential for dramatic new findings in infrared and radio astronomy—demonstrated by the Cosmic Background Explorer (1989) and reflected in planning for the European Space Agency's Infrared Space Observatory (1995)—will increase significantly when the Stratospheric Observatory for Airborne Astronomy (SOFIA) and Space Infrared Telescope Facility (SIRTF) become operational.

Moreover, the value of data in specific spectral bands can be enhanced by multispectral studies that cut across spectral boundaries to integrate data obtained by different space missions. The same phenomenon, such as a jet of matter emerging from a galactic nucleus, often has a different appearance in different spectral bands; multispectral data studies help to build up a complete picture of the phenomenon and multiply the scientific return from individual missions.

The challenge of processing, analyzing, and interpreting these future data volumes at acceptable cost can only be met through the greater efficiencies of advanced technology and techniques. Continued investments in data handling and analysis technology will therefore be needed to ensure that NASA reaps the scientific return on previous investments in spaceflight hardware.

Mission Operations and Data Analysis



19. Leadership in Technology

The technology developed today is used in the science of tomorrow. Investment in new technology must be continued to maintain the NASA Astrophysics tradition of leadership in technology and science.

The spectacular successes of space astronomy over the past few years—e.g., the all-sky mapping of infrared sources by NASA's Infrared Astronomical Satellite and measurements of the cosmic background radiation by NASA's Cosmic Background Explorer—are the direct result of earlier investments in technology. The agency has in some cases inherited or borrowed technology from military sources. In most cases, however, NASA programs depend on technology development undertaken or sponsored by the agency itself. The future of NASA space astronomy is thus linked closely to investments in advanced technology made by the Astrophysics Division.

Among the key technology areas are radiation detectors covering almost all regions of the spectrum, optics (e.g., lightweight mirrors and X-ray focusing systems), instrumentation, support structures and observing platforms, and detectors for the gravitational waves predicted by Einstein's General Theory of Relativity.

Support provided to these areas through the Division's Supporting Research and Technology (SR&T) program is vital to generate the new technology needed for later missions. Consider, for example, interferometry. This technique, long used in radio astronomy with spectacular results, employs two or more widely spaced collectors to achieve the high spatial resolution (ability to record fine detail) of a very large single collector. If developed for the visible and ultraviolet spectral bands, a space interferometer could make astrometric and other ultrahigh-resolution measurements needed to investigate many forefront questions in astronomy. A space-based Astrometric Interferometry Mission (AIM) was in fact recommended for implementation during the 1990s by the National Academy of Sciences' Astronomy and Astrophysics Survey Committee.

Unless long-range work on these and other advanced technologies is supported now, NASA's capability to carry out forefront missions in the next decade and beyond will be seriously and perhaps permanently compromised.

Astrophysics

Leadership in Technology

New Technology: 1990s

- Optics
- Radiation Detectors
- Instrumentation
- Structures
- Observing Platforms
- Gravity - Wave Detectors

New Missions: 2000 –

- Interferometers (Ultrahigh Spatial Resolution)
- High - Throughput Optics
- Large Deployable Collectors
- Gravity - Wave Detection
- Lunar Astrophysics

New Knowledge: 2005 –

- Cosmic Distance Scale
- Age of the Universe
- Properties of Black Holes
- Dynamics of Galaxy Formation

20. Education and Public Outreach

No field of science can match the inspiration and visual excitement of astronomy. The Astrophysics Division's education and public-outreach program, established in 1991 to supplement more general NASA educational and public-information efforts, is closely aligned with national education goals.

Pulsars, quasars, galaxies, space-warp, black holes. These terms and images are now part of our culture, appropriated by advertising and beamed back to us by television and video games. The reason is simple: astronomy takes us away from the mundane Earth and out into the splendor of the cosmos. And astronomy is a highly visual science, replete with images that illustrate the operation of scientific laws throughout the Universe.

In 1991, responding to recommendations of the National Academy of Sciences' Astronomy and Astrophysics Survey Committee, the Astrophysics Division decided to initiate its own education and public-outreach program. A new umbrella program, the Initiative to Develop Education through Astronomy (IDEA), was begun to embody the Division's commitment to pre-collegiate and public learning in support of national education goals.

IDEA makes use of small funding augmentations and modest efforts by scientists to produce a large impact on education. Drawing on both professional and amateur astronomers as participants, the program aims to (1) enhance the mathematical, technological, and scientific literacy of all Americans; (2) promote learning and study in every area, particularly at the elementary level, by integrating the excitement of astronomy into the everyday school curriculum; (3) increase the representation in science of minorities and women; and (4) improve the accuracy and quality of astronomical information available to the public.

First of all, IDEA facilitates the participation of the space-astronomy community, primarily through provision of modest funding for time and materials. In addition, IDEA capitalizes on the unique features of space-astronomy missions, such as the renown of the Hubble Space Telescope and the educational opportunities offered by the Kuiper Airborne Observatory (KAO). Finally, IDEA brings the excitement of astrophysics directly to the student, teacher, and public through the sponsorship of space-astronomy educational materials and teacher participation in conventions and workshops.

Among the IDEA projects to date are: (1) educational supplements to astrophysics research grants; (2) flight opportunities for teachers aboard KAO; (3) the "Ask An Astronomer" traveling exhibit, staffed by local astronomers and featured at science-teacher conventions and other gatherings; and (4) production of a wide variety of classroom materials. These efforts are supplemented by other NASA programs, such as the "Space Astronomy Update" television program aired regularly over the NASA Select channel. The Astrophysics Division will continue to strongly support education and public outreach in the future.

Education and Public Outreach

Papanui Elementary School students visit
Kuiper Airborne Observatory in New Zealand

Near-Term Objectives

- Use excitement of astrophysics to further educational goals.
- Increase participation of astrophysics community in educational activities.

Long-Term Goals

- Raise American scientific literacy.
- Improve astronomy information content and presentation.
- Integrate astronomy into curriculum.

21. Implementation of Guiding Principles

NASA Astrophysics missions and programs implement the Division's Guiding Principles which, in turn, reflect the Astrophysics Vision at the heart of this integrated research, education, and public-outreach effort.

NASA's Astrophysics program is a coherent and unified network of missions, projects, and individual programs, all of which combine to implement the Division's Guiding Principles and attain the Astrophysics Vision.

The Great Observatories (the Hubble Space Telescope and Compton Gamma Ray Observatory, to be followed by the Advanced X-Ray Astrophysics Facility and the Space Infrared Telescope Facility) lead the opening of major scientific frontiers. Intermediate missions (e.g., the Submillimeter Intermediate Mission) and Space Shuttle-attached payloads (e.g., the ASTRO-2 ultraviolet mission) pursue discoveries made by other experiments in space.

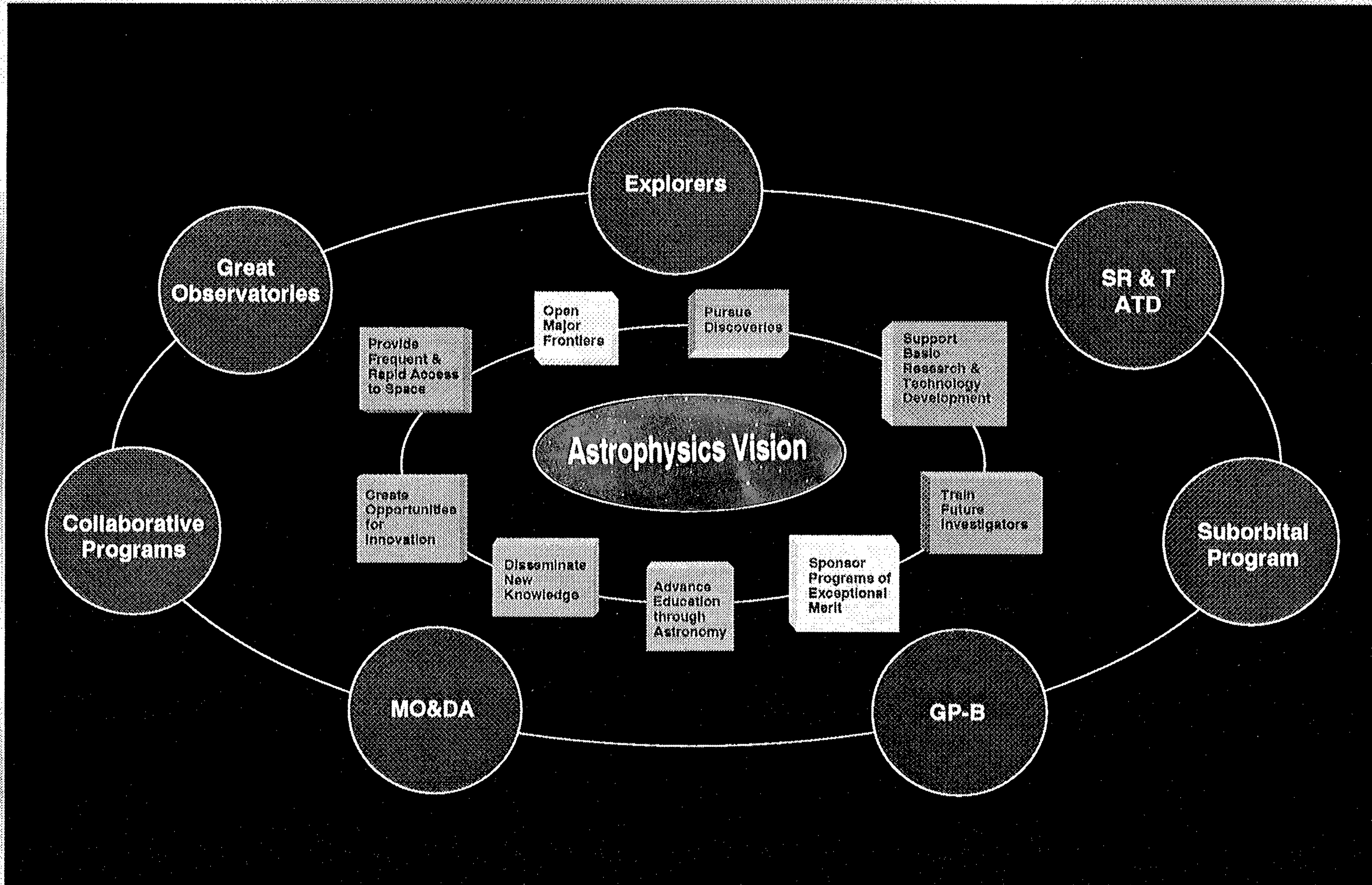
Explorer and collaborative missions provide frequent and rapid access to space. In the past, Explorers like the Infrared Astronomical Satellite (IRAS) provided high capability but required long development times. Future Explorers will follow the example of the first of the Small Explorer missions—the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX)—which required less than four years from selection to launch. Collaborative missions like ALEXIS (a joint project of DoD, DoE, and NASA) also permit rapid launch and incorporation of the latest instrument technology. Both the Explorers and collaborative missions thus create opportunities for innovation as well.

The suborbital missions—balloons, rockets, and aircraft—help to train the next generation of investigators. Instruments for these vehicles can be designed, fabricated, and flown within the typical 5-year graduate-student training period. The student also can participate in every phase of the mission, from original proposal to publication of the data and their interpretation.

However, implementation of the Guiding Principles is not restricted to flight missions. The Division's Initiative to Develop Education through Astronomy (IDEA) advances national education goals using the unique appeal of astronomy. The Research and Analysis (R&A) program provides investments in the future through basic research and technology development. And the Division's Mission Operations and Data Analysis (MO&DA) program permits both NASA and the scientific community to produce, analyze, and disseminate new knowledge efficiently.

Finally, there must always be provision at NASA and the Astrophysics Division for scientific programs of exceptional merit—those that address questions on the grandest scale, promise new knowledge at the very foundations of science, and push the frontiers of technology far beyond current capabilities. NASA's proposed Gravity Probe-B mission certainly meets these criteria.

Implementation of Guiding Principles



22. Other Benefits to Society

NASA's space-astronomy program does more than provide new knowledge. It also advances pre-college education, promotes the transfer of publicly funded technology to the private sector, and creates new avenues for international understanding.

The benefits of NASA's space-astronomy program extend far beyond the contribution of new knowledge and understanding of the Universe.

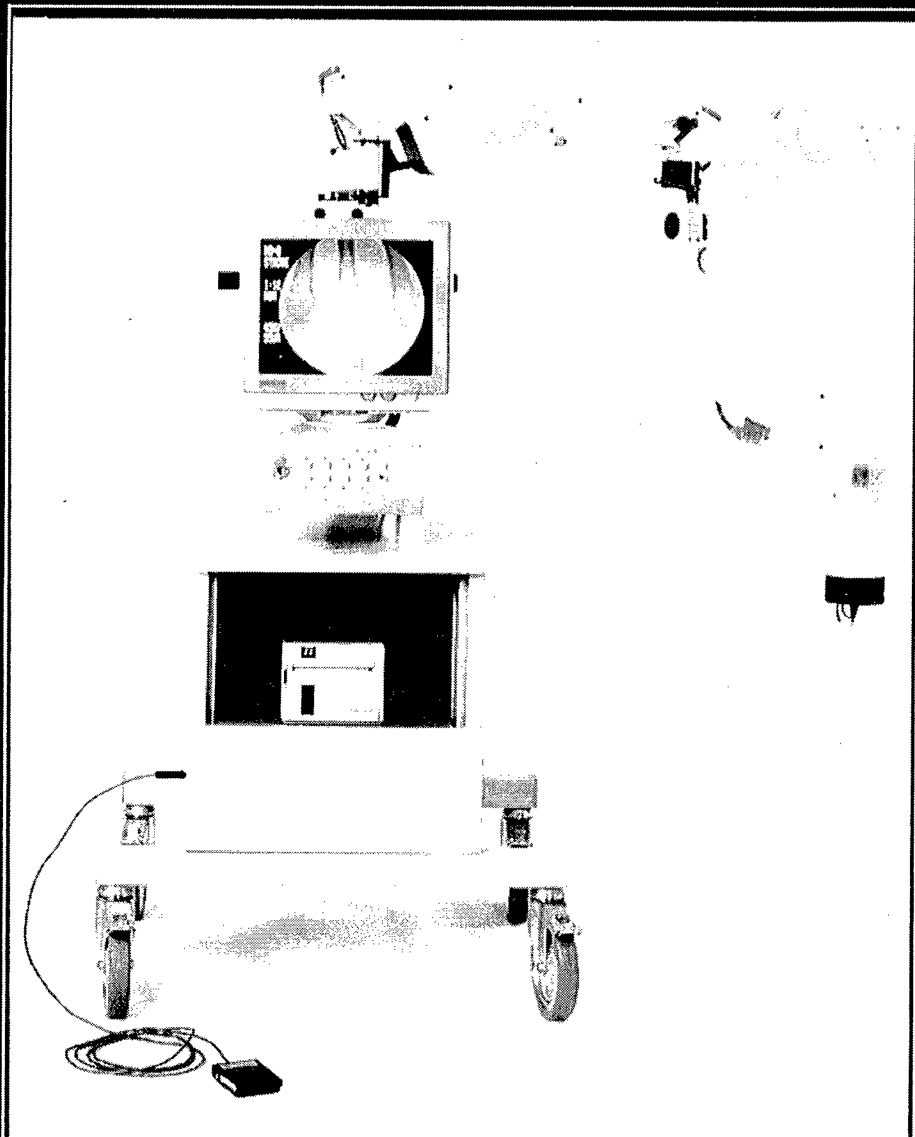
One benefit is the advancement of pre-college education. Space astronomy furnishes not only content for the classroom, but also approach and technique. For example, planetary and satellite motions exemplify the laws of mechanics; telescope design illustrates the laws of optics; and stellar atmospheres display the effects of radiation emission and absorption. NASA's IDEA project—the Initiative to Develop Education through Astronomy—is already helping to turn student interest into action.

A second additional benefit is the transfer of astrophysics technology to the private sector. Recent space-science successes are the direct result of past investments in technology, and some of these are now in the American commercial marketplace. FluoroScan Imaging Systems, Inc. of Northbrook, Illinois has applied astrophysical X-ray imaging technology to medical diagnostic imaging; Diatek Corporation of San Diego, California, has adapted infrared-sensor technology for use in a new ear-mounted medical thermometer (NASA Spinoff 1991, pp. 58 and 80). And Richard Hoover, an X-ray astrophysicist at NASA's Marshall Space Flight Center, was named NASA Inventor of the Year for his revolutionary new X-ray microscope; the instrument has such high spatial resolution that it may ultimately produce detailed images of DNA molecules—the building blocks of life.

Finally, NASA collaboration with other nations contributes to international understanding through direct contact of scientists and engineers in an atmosphere of openness and mutual respect. The NASA Astrophysics Division has flown experiments in collaboration with Japan and most of the nations of Western Europe, and is now reaching out to South America and the rest of Asia. Collaborations or joint space missions continue to be a strong link between the U.S.A. and Russia and other republics of the former Soviet Union.

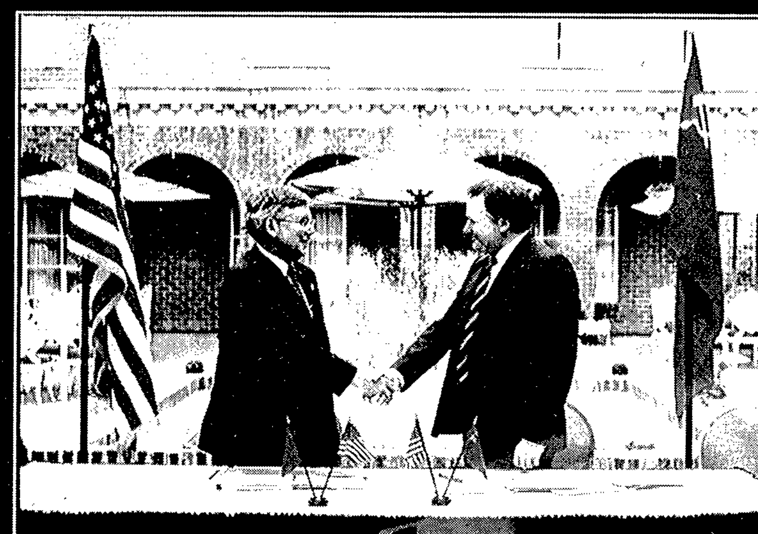
Astro physics

Other Benefits to Society



FluoroScan X-Ray Scanner

Education



International Understanding

23. Tributes

There is growing public recognition of NASA's achievements in space science, and particularly in space astronomy.

Less than three years ago, the national press was taking NASA to task for a flaw in the Hubble Space Telescope (HST) mirror. But now, after more than two years of routine operation, HST has suprised its early critics by returning new knowledge at the frontiers of science. The first HST servicing mission by the Space Shuttle, currently scheduled for the end of 1993, should permit the telescope to achieve nearly all of its original scientific objectives over a planned 15-year mission lifetime.

Moreover, NASA's second Great Observatory—the Compton Gamma Ray Observatory, now in its second year of operation—also is performing well. CGRO has found that the enigmatic gamma-ray "burst" sources are distributed uniformly over the sky, rather than being concentrated toward the plane of our Galaxy, as had been predicted. Their nature and cause are still unknown.

There have also been triumphs elsewhere in NASA's space-astronomy program. The two most recent Explorer missions, for example, have both been resounding successes.

Analysis of data from the Cosmic Background Explorer (COBE), launched in 1989, has now revealed a granularity in the cosmic background radiation that is believed to reflect galaxy formation in the earliest stages of the cosmic expansion—a key piece of the cosmology puzzle that had been missing earlier.

And the Extreme Ultraviolet Explorer (EUVE), launched in 1992 for studies of such extreme-ultraviolet sources as hot white-dwarf stars, has successfully completed the first survey of the sky throughout this little-explored spectral region, and has now begun to carry out the first detailed spectroscopic studies of extreme-ultraviolet sources.

These achievements have been extensively covered by the national press. Consider, for example, *Science News*, the nation's leading popular scientific weekly. Of the 172 most important *Science News* stories for 1991, nineteen were NASA-related, and eight of these described the results of Astrophysics missions. The figures for 1992 are comparable: of 181 major *Science News* stories, twenty were NASA-related, and twelve of these dealt with Astrophysics missions. The more general trade magazine *Aviation Week and Space Technology* also follows the NASA space-astronomy program closely, as do many other scientific and technical periodicals.

But coverage of NASA Astrophysics achievements has not been limited to publications targeted at scientific and technical readers. There has been a recognition that these achievements are a source of pride to the nation at large. Major newspapers—for example, The Philadelphia Inquirer, The Washington Post, and USA Today—have joined with such mainstream magazines as *U.S. News* and *Time* to pay tribute to NASA as well. Among the stories covered are new findings by the Cosmic Background Explorer (COBE), Hubble Space Telescope (HST), and Compton Gamma Ray Observatory (CGRO).

Moreover, in its January 4, 1993 selection of "Ten Major Science Advances for 1992," *Time* magazine awarded its No. 1 ranking to "The Big Bang" (COBE) and its No. 4 ranking to "Hubble's New Image" (HST).

Astro physics

Tributes

COBE

TIME

ECHOES OF THE BIG BANG

They were, by far, the largest and most distant objects that scientists had ever detected: a swath of gargantuan cosmic clouds some 15

By peering back into the beginning of time, a satellite finds the largest and oldest structures ever observed -- evidence of how the universe took shape 15 billion years ago ...

USA TODAY

NATIONLINE

Relics of universe's birth found

'It's like looking at God,' says astrophysicist

Truth, after all, is its own reward. And the truth about the origins of the universe ...

HST

& WORLD REPORT

Knocking on heaven's door

SCIENCE & SOCIETY

Ever since Galileo turned the first telescope skyward in 1609, each improvement in astronomical instruments has uncovered phenom-

The Hubble Space Telescope was able to gaze inside a distant galaxy revealing massive clusters of young stars never seen before.

The Washington Post

Colliding Galaxies Create A 'Supernova Factory'

Hubble Provides Insight on Star Formation

...announced detection of " a new class of object in the universe," gigantic and violent star forming clusters... created from the wreckage of two galaxies that are colliding.

CGRO

AVIATION WEEK & SPACE TECHNOLOGY

Data From Hubble, GRO Likely To Shake Astronomical Theory

ATLANTA–
Two spacecraft that are still early in their international scientific missions–the Hubble Space Telescope and the Compton Gamma Ray Observatory– have begun to produce data likely to "rewrite the books" in astronomy

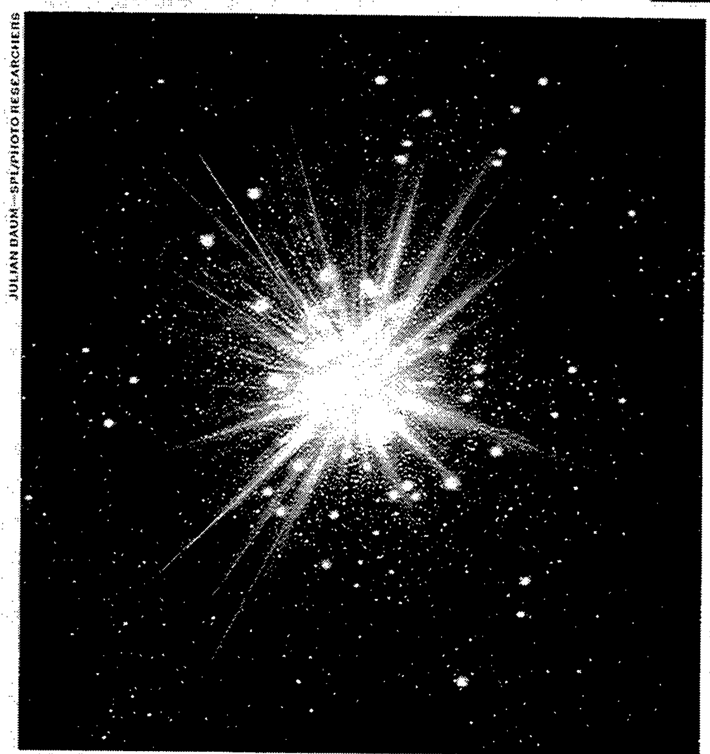
It was the first broad indication that the satellites would live up to NASA's prelaunch descriptions of them as "great observatories."

The Philadelphia Inquirer

Scientists stunned by gamma-ray discovery

... findings, from NASA's massive Gamma Ray Observatory

... indicate that the sources of the bright bursts could be very close objects with relatively modest firepower, or they could be enormously distant cataclysms... greeted by scientists as "astounding" and "mind blowing."



JULIAN DAUM—SPL/PHOTO RESEARCHERS

1 The Big Bang **Peering back to the edge of time, the Cosmic Background Explorer satellite took snapshots of light generated nearly 15 billion years ago and found the best evidence yet for the Big Bang. Peppered throughout the light, COBE found faint hot spots that were just 30 millionths of a degree warmer than their surroundings. These anomalies mark places where matter was a bit denser than average. Without those areas, the matter spewed out by a Big Bang could never have evolved into galaxies. The next challenge: finding the invisible "dark matter" that helped shape the modern universe.**

2 Anti-Cancer Gene

It sounds like a leftover from World War II, but P53 is actually the hottest new weapon in the fight against cancer. Under normal conditions, this gene stops tumor cells from growing. Whenever DNA is damaged, P53 shuts down a cell's growth until the error can be fixed. But if the watchdog gene is disabled, wayward cells can divide unchecked. Although doctors cannot yet fix a broken P53 gene, they can detect it and thus diagnose a hidden malignancy.

NICHOLAS CLAPP

3 The Lost City of Ubar

Two thousand years ago, Ubar—fabled for its frankincense—sank beneath the Arabian sand. The city was unearthed last year by archaeologists using pictures taken from spacecraft. The radar images pierced the dunes to reveal abandoned caravan routes converging on the city that, according to legend, God destroyed for its wickedness. Note of caution for the excavators: an old Arabian saying holds that "anybody who finds Ubar will go crazy."

4 Hubble's New Image

First the Hubble Space Telescope was going to revolutionize astronomy with its supersharp vision. Then it was condemned as a $1.5 billion dud when its mirror was found to have the wrong shape. The latest take: it's not perfect, but even a nearsighted Hubble is pretty powerful. It has spotted the most distant clusters of stars ever seen.

5 The Anti-Smoking Trend

Concern about the health hazards of tobacco is mounting around the world. The number of Americans who smoke reached a record low last year as nonsmokers outnumbered smokers nearly 3 to 1. France adopted a law that restricts smoking in public places, and China, the world's largest producer and consumer of tobacco, now bans advertising.

SIPA

6 Plastic Plants

Taking a cue from Rumpelstiltskin, who spun straw into gold, botanists managed to coax a lowly potted plant into producing plastic. Using genetic-engineering techniques, researchers redirected the plant's starch-storing apparatus into making PHB, a plastic that is biodegradable.

7 Dinosaur King

Tyrannosaurus rex may have been knocked off its throne as the meanest monster of the Mesozoic era. Paleontologists in Utah uncovered the claw, skull and jawbones of a 7-m (20-ft.), 1-ton beast that is the largest known specimen of a velociraptor—an upright carnivorous dinosaur with a huge claw on the back of each foot.

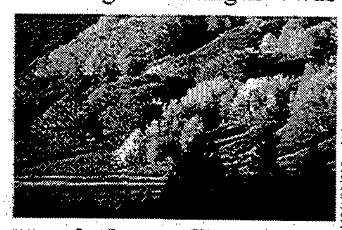
DINAMATION INTERNATIONAL SOCIETY

8 Lilliputian Batteries

With the help of electron microscopes, scientists can now manipulate atoms as if they were Lego building blocks. In August researchers at the University of California at Irvine unveiled the world's smallest battery—a sliver of graphite one one-hundredth the size of a red blood cell topped with terminals made of copper and silver atoms. The power output is twenty one-thousandths of a volt—not enough to keep the Energizer bunny going and going, but a good start.

9 The Mammoth Fungus

It started when some scientists argued that an ancient fungus, which grows in Michigan and Wisconsin under 12 hectares (30 acres) of forest, was one gigantic organism. But rather than establishing an undisputed record for the world's largest living thing, the claim triggered a new game of one-upmanship. Soon a bigger Washington fungus was named champ. Then Coloradans touted a 43-hectare (106-acre) grove of identical quaking aspens, pictured above, which share the same root system. What next—a planet-size organism named Gaia?



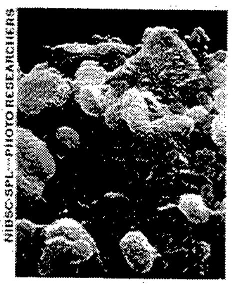
DR. JEFFRY MITTON—UNIVERSITY OF COLORADO

10 Milk

A handful of pediatricians tried to warn parents against serving milk, even low-fat, on the theory that kale has all the calcium any child would ever need. But moms and dads wisely ignored the advice—probably because they know how much kale a child would eat. ■

CLIFF FEULNER—THE IMAGE BANK

. . . AND THE WORST



NIBSC-SPL—PHOTO RESEARCHERS

Microbes Redux

Standard treatments proved increasingly ineffective against new strains of tuberculosis, gonorrhea and malaria. The comeback of those old scourges compounded the relentlessly grim news about AIDS, which has struck as many as 1.5 million people. One ominous sign: that epidemic is now growing almost as fast in Asia as in Africa.

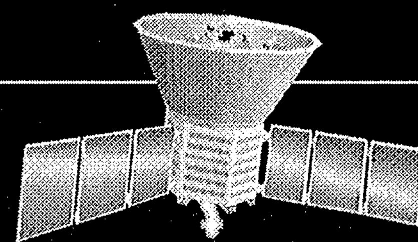
Astro physics

TIME

4 January 1993

Ten Major Science Advances for 1992

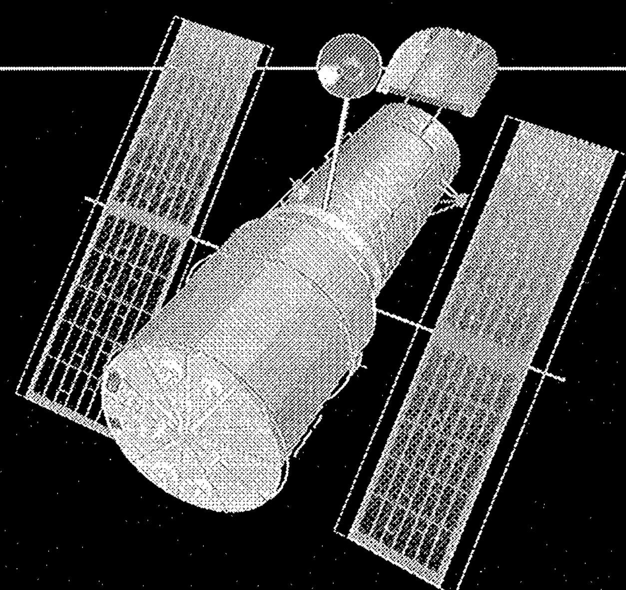
1. The Big Bang



Cosmic Background Explorer

2. Anti-Cancer Gene
3. The Lost City of Ubar

4. Hubble's New Image



Hubble Space Telescope

5. The Anti-Smoking Trend
6. Plastic Plants
7. Dinosaur King
8. Lilliputian Batteries
9. The Mammoth Fungus
10. Milk